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Testing the Weak Form of Efficient Market Hypothesis in Stock Markets

Testování slabé formy efektivního trhu na akciových trzích

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Declaration of Utilisation of Results from the Diploma Thesis
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Annexes

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The declaration

“Herewith I declare that I elaborated the entire thesis, including all annexes, independently. ”

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Signature

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1. Introduction

The financial market is defined as a market in which people trade securities, commodities and so on. There exist developed markets and emerging markets, and there are many differences between these two types of financial markets. In general, emerging markets would be accompanied by greater risk in investment than developed markets.

The stock market is one of the most important components of financial market. It is influenced by many factors, such as policy, situation of economy and investor's behavior. Therefore, there may exist linear and nonlinear dependencies within stock returns and trading volume in stock markets.

In stock market, the purpose of investors is through buying and selling stocks to obtain profit. In order to realize this purpose, they apply many tools and methods. This is related to efficient market hypothesis since investors look for imperfections in markets to get a profit.

This thesis is focused on testing the information efficiency of different stock markets. Efficient market hypothesis is a very important theory related to stock markets. In efficient market, stock prices can reflect all information. According to the degree of reflecting information, the efficiency can be divided into weak form, semi-weak form and strong form.

If the market is not effective, investors can obtain excess returns through a variety of analysis. Fundamental analysis and technical analysis are the most frequently used methods.

In general, developed markets are usually more efficient. Therefore, public information disclosure system is a necessary condition of establishing efficient market.

Emerging stock markets, like Chinese stock market, has become more and more important in the global market. That is why one can be interested to analyze differences in efficiency between developed and emerging stock markets.

The aim of this thesis is to test the weak form of efficiency in different stock markets using linear and nonlinear methods. For the purpose of this thesis, we use daily time series of Chinese, Japanese and British stock markets covering the period from 01/01/2003 to 10/30/2015. In the case of Chinese stock market, we will work with data from Shanghai stock market and Hong Kong stock market, since they exhibit different characteristics. Shanghai stock market is represented by Shanghai composite index, while Hang Seng index is a representative of Hong Kong stock markets. Japanese market is approximated by Nikkei 225 index, and FTSE 100 index is a representative of British stock market.

The main aim of this thesis is supported by three sub-goals: The first sub-goal is to compare results achieved by linear and nonlinear methods of testing the efficiency on stock indexes.

The second sub-goal is to compare the difference of results between Shanghai stock market and Hong Kong stock market. Shanghai stock market belongs to emerging stock market, while Hong Kong is considered a developed stock market.

The third sub-goal is to evaluate an impact of global financial crisis on efficiency of investigated stock markets.

The whole thesis is divided into 6 parts, including "Introduction" and "Conclusion". Furthermore, part 2 and part 3 constitute theoretical and methodological background, while part 4 is focused on description of testing methods applied in this thesis, and part 5 is purely practical or empirical part of this thesis.

Chapter 2 will briefly introduce basic approaches to analyse stock market, since the object of this thesis are stock markets. The basic approaches include fundamental analysis, technical analysis and psychological analysis.

Chapter 3 plays an important role in this thesis, since it describes efficient market hypothesis in detail. This chapter includes definition of efficient market hypothesis, its forms, assumptions, characteristics and theoretical models. In this part, we emphasize weak-form of efficiency, since we will test the weak-form in following chapter. Furthermore, the description of martingale, fair game and random walk models is the foundation for practical part. In the end of this chapter, there will be introduced some studies on testing the weak form of efficient market hypothesis.

Chapter 4 includes methods for testing information efficiency. These methods can be divided into linear methods and nonlinear ones. The linear methods that are to be introduced contain variance ratio test, Ljung-Box test and runs test. At the same time, the nonlinear methods include White test, Engle's test and BDS test. This chapter also refer to the possible problems of testing efficiency and features of financial time series.

In Chapter 5, we will firstly introduce the stock exchanges for China, Japan and UK.

Especially in Chinese stock exchanges, there are many special trading rules in Shanghai stock exchange. The basic testing period will be divided into three time sub periods. Moreover, we computed descriptive statistic for return series. Next, linear methods and nonlinear methods will be applied to verify efficient market hypothesis in different stock markets during all three sub-periods. Finally, an overall summary of results will be delivered.

In Conclusion we summarize and comprehensively evaluate the whole thesis. We evaluate whether the main goals and sub-goals of this thesis are fulfilled and indicate the potential shortcomings which can be improved.

In this diploma thesis, all original data are received from public sources, and all tables and figures are made by own calculations using EViews 7 and Microsoft Excel.

2. Basic Approaches to Analyse Stock Markets

This chapter simply introduces three types of analysis of stock markets: fundamental analysis, technical analysis and psychological analysis. All these approaches are related to the efficiency market hypothesis in some way. These analyses provide basic knowledge of stock markets. The fundamental analysis will be viewed from three parts: global analysis, sector analysis and the analysis of particular company. The technical analysis will also be divided into three parts: graphical methods, methods based on technical indicators and the Dow Theory. Additionally, some definitions and explanations of terminologies for technical analysis will be introduced briefly by Fama (1970) and Campbell (1997).

2.1 Fundamental Analysis

Fundamental analysis is a method which uses financial analysis and economic research to evaluate enterprise value or predict trend in value of securities (such as stocks or bonds, etc.). Fundamental analysts attempt to research everything that can affect the security's value; usually it includes the company's financial statements and non-financial information, such as macroeconomic factors (like the growth of GDP, inflation, the influence of the new system or change in the population, etc.), industry conditions (like enterprise comparisons, etc.) and company information (like forecasts of demand growth, etc.). We can obtain some information about fundamental analysis by Murphy (1999).

In fundamental analysis, if the investors want to make money in the long-term, they should focus on the company itself, and not just in its share price. The fundamental analysis is based on idea that the intrinsic value of the company will be reflected in stock prices at the end. But in fact, no matter how effective the market is, the price will be overvalued or undervalued in the short-term.

When investors use fundamental analysis to predict the value of company, they can compare it with the security's current price. If the value is underpriced, investors can buy the stock. On the contrary, if the value is overpriced, investors can sell the stock.

The disadvantage of fundamental analysis is that it involves too much information, so it's difficult to collect information completely. If investors want to do a comprehensive analysis, they should have a variety of professional knowledge. By the time investors get the results from the analysis, the information may have already changed.

Fundamental analysis usually be used to analyse the stock markets, and this analysis can be divided into three parts: global analysis, sector analysis and analysis of particular company.

2.1.1 Global Analysis

Global analysis is a macroeconomic analysis, and it is a study of the behaviour of the economy as a whole. It includes economy-wide phenomena such as changes in unemployment, growth rate, gross domestic product, inflation and price levels, interest rates and so on.

The investors analyse the influence of these macroeconomics factors on stock value. They want to predict the direction of the economy and its future influence on the whole stock market.

GDP is commonly used as an indicator of the economic health of a country, as well as to measure a country's standard of living. For example, in China, the GDP growth rate was 7.4% in 2014. Although it is still among the highest in the world, it's clear that economic growth is slowing. It's expected that the GDP growth rate will continue to fall in 2015 and 2016.

In the business cycle, after a recessionary phase, the expansionary phase can start again. The phases of the business cycle are characterized by changing employment, interest rates and industrial productivity. In general, economists believe that stock price trends precede business cycle stages. Therefore, GDP is considered as a reliable indicator for forecasting changes of business cycle stages and the whole economy.

Nowadays, the world's economic ties are more and more tight. Globalization is a very important factor in global analysis, but if a crisis occurs, the domino effect may well influence global economy. For example, if Greece defaults on its debts, the effects spread to other Eurozone countries.

In the real global situation, the developed economies reflect a deepening economic divide, as the growth of the developing economies has slowed in recent years. Most major international organizations have reduced forecasts for world economic growth in many major economies.

Now the US economy has taken the lead in the recovery, and the Federal Reserve Board's anticipated decision to raise interest rates has attracted much attention.

Regardless of a number of problems, the Dow Jones index continues to rise, demonstrating the recovery of the stock market in United States. In 2015, China's stock markets have experienced higher volatility, while the US market has been relatively stable.

In August 2015, the China's currency devaluation and heavy selling of American Treasury Bills have led to the decline of global stocks. Global stock markets are closely linked, so quantitative easing and other problems like the drop in the price of crude oil make it difficult to predict the situation of the stock markets.

2.1.2 Sector Analysis

Sector analysis is also called industry analysis; the term sector is used to refer to a group of related industries. Dividing an economy into different segments allows for a deeper analysis of the economy as a whole. Industry analysis is useful in a number of investment applications. Each industry has differences in terms of its customer base, market share among firms, industry-wide growth, competition, regulation and business cycles. Learning about how the industry works will give an investor a deeper understanding of a company's financial health.

Investors could understand the company´s environment, insights into the growth opportunities and business risks, and the possibilities of financing. At same time, they could decide whether it is an active equity investment opportunity. It can be a positive, neutral or negative outlook for profitability and growth.

The classification of the industry may be divided into four parts by Porter (1980):

(1) Cyclical industry. Its performance is positively related to economic activity. Companies from these industries have large difficulties during recession, which can impact its stock prices.

(2) Neutral industry. It is not affected by the economic cycle. For example, it includes the production of essential goods, because it is not possible to leave their purchase for later.

(3) Defensive industry. Its performance is negatively related to economic activity. Profits of these companies are higher during recessions.

(4) Growth industry. It characterized by rapid growth in sales, regardless of the business cycle.

Investors should not always prefer industries with lower sensitivity to the economic cycle. Companies with sensitive industries can offer investors opportunities to earn money in stock markets.

There are four determinants of competition in industry:

(1) Threat of entry from new competitors. This means the barriers to entry can be a key determinant of industry profitability.
(2) Rivalry between existing competitors. Industries producing homogenous goods are subjects to considerable price pressure, because companies cannot compete on the basis of product differentiation.
(3) Pressure from substitute products. This means that the industry faces competition from companies in related industries.
(4) Bargaining power of buyers or suppliers.

One way to evaluate a company's growth potential is to research whether the number of customers in the overall market will grow, because without new customers, a company may have to steal market share from other companies in order to grow.

Certain industries have limited barriers to entry, and a large number of competing firms create a difficult operating environment for companies. The lack of pricing power is one of the biggest risks within a highly competitive industry. This refers to the ability of a supplier to increase prices and change the costs to customers. As important as some of governments' regulations are to the public, they can affect investment purposes to a company.

2.1.3 Analysis of Particular Company

The analysis of a particular company includes quantitative financial analysis, the calculation of intrinsic value, and a qualitative SWOT analysis.

The key financial ratios include profitability ratios, leverage ratios, liquidity ratios and so on. These ratios can measure management's ability to control expenses or to meet its current obligations. It's very useful for investors observing a company.

The intrinsic value of the company can be calculated by present value models or multiplier models. The present value model is a discounted cash flow model; it includes dividend discount models and cash flow models. The P/E, P/S, P/CF, P/BV formulas are very common in multiplier models.

The Dividend Discount Model (DDM) is used to evaluate stocks based on the net present value of the future dividends. In multiplier models, the P/E ratio is a stock´s current price divided by its earnings per share. If a company has a P/E higher than the market or industry average, this means that the market is expecting big things over the next few months or years. The last analysis of a particular company is the SWOT analysis. This is a tool that identifies the strengths, weaknesses, opportunities and threats of or to a company. The SWOT analysis takes information from an environmental analysis and separates it into internal issues (strengths and weaknesses) and external issues (opportunities and threats).

2.2 Technical Analysis

In this chapter, there will be introduced technical analysis to study the stock markets. The method of technical analysis include: graphical methods, methods based on technical indicators and the Dow Theory.

Technical analysis is the science of recording, usually in graphic form, the actual history of trading, such as the volume of transactions, price changes and so on, in a certain stock or in "the averages," and then deduces the probable future trend from that pictured history (Edwards, Magee and Basetti, 2007).

Technical analysis is a different approach compared to fundamental analysis. It doesn't care about the "value" of a company; it is only interested in the price movements in the market. It means that unlike fundamental analysts, technical analysts don't care whether a stock is undervalued or not. The only thing that matters is a stock's past trading data and what information this data can provide about a direction that the stock might take in the future.

There exist three assumptions of application of technical analysis are:

(1) The market discounts everything.

(2) Price moves in trends.

(3) History tends to repeat itself.

There have been developed more and more technical tools and theories and enhanced in recent years, with an increasing emphasis on computer-assisted techniques.

2.2.1 Graphical Methods

Graphical methods are the most important tools of technical analyses. Investors can obviously analyse the trends through the graphical methods.

In the stock's figure, the line chart has only the closing price for each successive day. Since the closing price is the most critical price of the trading day, a line chart can reflect price activity.

Figure 2.1 shows example of closing prices of the Shanghai composite index by using line chart.

Figure 2.1 A line chart of Shanghai composite index for five years.

Source: http://stockhtm.finance.qq.com/hqing/zhishu/000001.htm

A bar chart is a type of chart used by technical analysts on which the top of the vertical line indicates the highest price a security traded at during the day, and the bottom represents the lowest price. The closing price is shown on the right side of the bar, and the opening price is shown on the left side of the bar. A single bar represents one day of trading. Figure 2.2 shows example of closing prices of the Shanghai composite index using bar chart.

Figure 2.2 The Bar chart of Shanghai composite index for one month.

Source: http://www.tradingeconomics.com/china/stock-market

As shown in Figure 2.1, in early 2015, China's real economic growth was slow, and bank interest rates were low. Therefore, investors invested in the securities market, so the Shanghai composite index rose to more than 5,000 points. But the inflated index is not a positive phenomenon.

2.2.2 Methods Based on Technical Indicators

Technical indicators are a result of mathematical calculations based on indications of price or volume. They can be used to forecast probable price changes, like the Moving Average, Relative Strength Index, Bollinger Bands, On Balance Volume and so on. In this subchapter some definition will be introduced by Appel (1979).

A moving average is one of the most popular and easy to use tools available to the technical analyst. The two most popular types of moving averages are the simple moving averages (*SMA*) and the exponential moving average (*EMA*).

The SMA can be calculated as a sum of closing prices in a period of time divided by the number of days in that period of time. Namely, this is an average stock price over a certain period of time. It can be computed as:

$$\mathrm{SMA} = (C_1 + C_2 + C_3 + \cdots + C_N)/N, \tag{2.1}$$

where C_i can be defined as closing price in one day, for $i = 1,2,\ldots,N$, N can be defined as the number of days in a period of time.

EMA is similar to the simple moving average, except that more weight is given to the latest data. This type of moving average adjusts more quickly to recent price changes than a simple moving average, so it can adjust for the lag of price movements. It can be computed as:

$$EMA_t = \propto * C_t + (1-\propto) * EMA_{t-1}, \tag{2.2}$$

where $\propto$ is an exponential coefficient, generally calculated as 2/ (N+1).

According to the length of lag, we can distinguish short-term lines, middle-term lines and long-term lines. For example, when the short-term line from the bottom up crosses over the long-term line, it is a signal to buy. At this time the short-term line will increase the price trends. In contrast, when the short-term line crosses the long-term lines from top to bottom, it is a signal to sell. At this time the long-term lines will lower the price trends.

Relative strength index (*RSI*) compares the magnitude of recent earnings to recent losses in order to determine overbought and oversold conditions of an asset. It can be computed as:

$$RSI = 100 - 100/(1 + RS)\ . \tag{2.3}$$

where *RS* can be defined as the Average of x days' up closes / Average of x days' down closes.

In general, *RSI* value changes between 30 and 70. Usually a value above 70 indicates that the market has reached an overbought condition, thus the market prices will naturally move back. When the number falls to below 30 that is considered to be oversold, and market prices will rebound. This index is suitable for short-term investments in stock markets, and is an analytical method to decide whether to buy or sell.

Bollinger bands use a statistical principle to calculate the standard deviation of stock price and its confidence interval, which determine the extent of the stock price fluctuations and future trends.

The indicator can be characterized in graphical below by three lines: the top line and the bottom line can be as the pressure line and support line of stock prices respectively. Between the two lines there is an average stock prices line. When all three Bollinger bands lines increase at the same time, it means that stock prices term will continue to rise, and investors can hold on for the turnaround. In contrast, it can show that stock prices will continue to fall in the short term, so investors should sell stocks at the higher price.

On balance volume uses volume flow to predict changes in a stock price. In other words, when volume increases sharply without a big change of the stock's price, the price will finally jump upward, and vice versa.

2.2.3 Dow Theory

This theory's originator, Charles Dow, claimed that his theory should not be used to predict the stock market, or even to guide investors. He thought it could be a barometer to reflect the overall trend in the stock markets. But now most people use the Dow Theory as a form of technical analysis on stock price movement. In this subchapter some definition will be introduced by RHEA (1932).

In the Dow Theory, there are 3 basic assumptions:

a) A manipulation of the primary trend is not possible.
b) The market index reflects all available information.
c) Investors should use this theory as a set of principles and guidelines to assist them, and this theory provides a mechanism for investors that will help remove some of emotions from investing decisions.

In the Dow Theory, the concomitant movements are composed of three phases: the primary movements, the secondary movements and daily fluctuations. Primary movements represent the broad underlying trend of the market, and last from a few months to many years. It is the overall direction of the market, and is the longest lasting trend.

Secondary (or reaction) movements last from a few weeks to a few months, and run opposite to the primary trend. In a bull market, the secondary movement is considered a correction. In a bear market, secondary movements may also be called action rallies.

Daily fluctuations last from a few hours to a few days, and usually not more than a week, and they can move with or against the primary trend. This results from the imbalance of supply and demand over short periods of time.

There are three basic stages of primary bull markets:

(a) The first stage is the accumulation.
(b) This is big move in which earnings begin to rise again and confidence starts to rebound.
(c) Excessive speculation and the appearance of inflationary pressures is the final stage.

Based on the three stages of primary bear markets, we can describe:

(a) The first is distribution, after making a lower high, a break under the previous low would explain that this was the second stage of a bear market.

(b) The second is big move.

(c) The third is despair that the market will continue to fall until all bad news is reflected in the price.

2.3 Psychological Analysis

Psychology plays an important role in financial decision-making. Psychological analysis aims to track market behaviour by accounting for investors' beliefs, desires and fears. The decision-making process is based on making choices that result in the most optimal level of utility for the individual. Most conventional economic theories are created under the assumption that the people taking part in an activity are behaving rationally. In most situations, this assumption doesn't reflect how people behave in the real world.

Kahneman and Tversky (1979) researched human risk-aversion, and found that people's attitudes regarding the risks associated with gains are different from those with losses. This means that the assumption that humans always act rationally is challenged by their risk aversion behaviour.

Loss aversion, mental accounting, narrow framing, anchoring and overconfidence are five behavioural relevant characteristics. For example, everybody has his or her own anchor, so they use relevant benchmarks in comparing their investment portfolio.

Psychological analysis is based on the assumption that the behaviour of investors is a very significant price creator during very short periods. So the behaviour of investors can influence the market mainly for the short-term, though the impact can be very large. But psychological factors do not influence trends for long time in the market.

This type of approach reasons that the most important information available an understanding of how the mass of investors will behave, because that will mainly determine the basic direction of the market. Many investors are influenced by the behaviour of other investors. In other words, they buy stocks when other investors buy, and they sell stocks when other investors sell.

This approach can lead to a more accurate judgment of the market, but it is very difficult to comprehensively collect investor opinions to measure the attitude of the market, and it is difficult to know at what time investors will enter or exit the market.

There are some basic theories within psychological analysis: Keynes' investment psychology, speculative bubble theory, greater fool theory and so on.

For example, Keynes' investment psychology posits that people do not behave rationally. General optimism among investors (reflecting higher expectations of return) raises the demand for investment.

The greater fool theory means that the price of an object is determined not by its intrinsic value. A rational buyer can justified a given price under the belief that another person ("the greater fool") is willing to pay an even higher price.

A speculative bubble theory is caused by exaggerated expectations of future growth that could cause an increase in asset values.

3. Efficient Market Hypothesis

Chapter 3 will introduce the efficient market hypothesis, including its definition, forms, assumptions and characteristics. This is a very important theory regarding this thesis, which cannot be ignored, because we will use the methodology to deal with the stock's data. Some definition and explanations of terminologies for an efficient market were published by Fama (1970), Lo and MacKinlay (1988).

3.1 Definition of an Efficient Market

The efficient market hypothesis (EMH) originated in the early 20th century, the study origin of this hypothesis is Bachelier, a French mathematician, who studied the Brownian motion, and applied a statistical analysis method to the analysis of the stock yields.

M. Kendall (1953) studied commodity prices and stock prices in Britain and the United States with help of computers. He found that the randomness of the price changes, and prices went up or down regardless of past performance. M. Osbourne (1959) shown that it is impossible to distinguish the random number and the share price in the United States. Samuelson (1965) provided the first formal economic argument for efficient markets.

In contrast to Samuelson's approach to the efficient market hypothesis, Fama's (1965, 1970) seminal papers were based on his interest in measuring the statistical properties of stock prices, and used technical and fundamental analysis. Roberts (1967) made the distinction between weak and strong form tests, which became the classic classification in Fama (1970).

Finally, the efficient market hypothesis was firstly defined by Eugene Fama (1970). According to Fama, the efficient market is defined as the following: if in a securities market, the prices always fully reflect all available information, the market is called an efficient market.

In an efficient market, stock prices maybe should follow a random walk. If prices are determined rationally, then only new information will cause them to change. A random walk will be the natural result of prices that always reflect all current knowledge. Much of the efficient market hypothesis (EMH) literature revolves around the random walk hypothesis (RWH) and the Martingale model. These are two statistical descriptions of unpredictable price changes. RWH and martingale model will specifically be introduced in subchapter 3.6.

The efficient market includes capital market efficiency, informational efficiency, and prices that fully and instantaneously reflect all available relevant information. There are no undervalued or overvalued securities. If the market is efficient, the best estimate of a security fair price is its market price.

The efficient market usually can be divided into an internally efficient market and an externally efficient market. The internally efficient market is an operationally efficient markets. It mainly measures the cost of trading when investors are buying and selling securities. An effective external market is also known as a pricing efficient market. This involves discussing whether the prices of securities quickly reflect all information about the price, and this thesis explores this concept.

According to the efficient market hypothesis, no single investor is ever able to attain greater profitability than another; since they have the same information. This means they can only achieve identical returns. If one investor is profitable, it means the entire market of investors is profitable. In fact, this is not possible. Everyone is not always rational, and the information is not accurate at every point in time. So economic bubbles and “irrational exuberance” always exists in real life.

The EMH, along with all of its behavioural alternatives, have led to a new hypothesis, the adaptive markets hypothesis, which is proposed by Lo (2004). The adaptive markets hypothesis can be viewed as a new version of the EMH, derived from evolutionary principles.

3.2 Forms of Efficient Markets

For the purpose of this thesis, we will deal with three forms of efficient markets: a weak form, a semi-strong form and a strong form. They are levels of market efficiency.

In efficient markets, the important thing is to classify the forms. The forms of efficient markets will be introduced in this subchapter.

In this thesis, only the weak form of efficiency will be tested in a later chapter. We will compare some different stock markets by testing the weak form of efficiency.

In the real world, strong form efficient markets are rare. Grossman and Stiglitz (1980) said that perfectly efficient markets are an impossibility. If markets are perfectly efficient, there would be no reason to trade and markets would eventually collapse.

Weak Form of Efficiency

In the weak-form of efficiency, future prices cannot be predicted from the analysis of past stock price data. The market price has already reflected the past stock's price information, including stock prices, volume, financing amount and so on.

Excess returns cannot be earned in the long run by using investment strategies based on historical stock prices or other historical data. So technical analysis and trend analysis will not be able to produce excess returns. The technical analysis was introduced in subchapter 2.2. However, fundamental analysis may still provide excess returns, this analysis was described in subchapter 2.1.

If a market is efficient in its weak form, the stock price may not accurately reflect the company's present and future, but do reflect the past. If a market can't reach weak efficiency, it means maybe the listed company has not completely disclosed its own history.

Semi-weak Form of Efficiency

When considering the semi-weak-form of efficiency, it is assumed that stock prices adjust to new publicly available information very quickly, so that stock prices fully reflect all public information about the prospects of a company operation. This information includes such items as price, volume, profit information, earnings forecasts, the company's management, and other public financial information.

If this semi-weak-form efficiency hypothesis is set up, no excess returns can be earned by fundamental analysis and technical analysis. However, abnormal returns can be acquired only on the basis of inside information.

In general, economists use the event study method to test the semi-weak form of efficiency. The events usually refer to the company released information, some specific behaviour of the company (such as distribution of dividend) or government behaviour (such as relevant legal amendments).

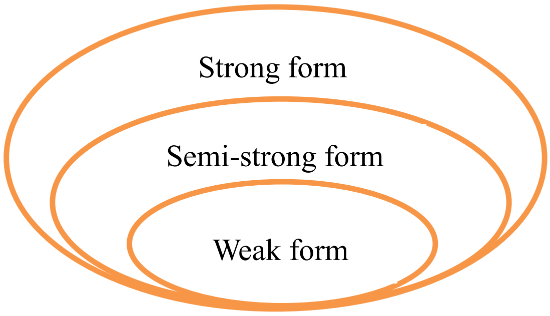
Strong Form of Efficiency

In the strong-form of efficiency, stock prices reflect all information, including public and private information, and no one can earn excess returns. If there are legal barriers to private information becoming public information, as with insider trading laws, the strong-form efficiency hypothesis is impossible, except in the case where the laws are universally ignored.

The test of strong form is focused on the yields of the professional investors or insiders. If the professional investors repeatedly have beyond-market performance, it means that the investors have the ability to predict. But if the market has strong efficiency, some knowledge is not reflected in the market prices.

Figure 3.1 demonstrates the relationship among different forms of efficient markets, according to different levels of information that are reflected into the securities prices.

Figure 3.1: The relationship between different forms of efficient market.



Source: Own

If the market is efficient in its strong form, the market must be efficient in its semi-weak form. Moreover, if the market is efficient in its semi-weak form, the market must be efficient in its weak form. This order cannot be reversed. It should be tested the weak form efficiency firstly.

3.3 Relation between Efficiency of Stock Markets and Equity Inner Value

In general, the price of the stock in the stock market fluctuates around the equity inner value. In the stock market, the stock price is determined by the intrinsic value of the stock. When the market needs to adjust, and the market lacks funds, stock prices are below than the intrinsic value of the stock. When the market is flourishing, there are sufficient funds in the market, so the stock prices are generally higher than their intrinsic value.

However, in efficient markets, stocks are traded at their fair value on stock exchanges, making it impossible for investors to either purchase undervalued stocks or sell stocks for inflated prices. In the efficient market theory, the price of the stock should fully reflect all information in the efficient stock market, so the stock prices can't deviate from their intrinsic values.

For example, in the current world, the most prominent investment manager is Warren Buffett. He has his own unique investment idea, and it has made a great success in practice. Buffett mainly engaged in the securities market to invest. His investment selection criteria considers the enterprise's intrinsic value.

In fact, he is looking for undervalued stocks in which to invest. Buffett believes that the market is sometimes inefficient, since people have fear, greed and follow behavioural trends. However, these situations are temporary. Buffett also thinks that the market is usually effective, because "lies" will be revealed.

If an excellent quality company has been vilified temporarily and misunderstood, and therefore its stock is undervalued, he will take investment action quickly. In an economic recession, rational investor will strive to acquire high-quality company stocks at low prices. Buffett became a world-famous investor because of this investment strategy and skills. Moreover, in less than half a century, he has already enlarged his initial capital more 30,000 times.

3.4 Assumptions of Efficient Market Hypothesis

It is very important to describe the assumptions of the efficient market hypothesis. In general, there exist 6 basic assumptions of EMH:

a) The market should reflect new information immediately, and adjust to the new prices. The price change depends on the occurrence of new information, and stock price present in a random fashion.
b) The occurrence of new information is random, so positive or negative information can occur.
c) There are many rational investors in the market who are pursuing maximum profits, and everyone is independent from stock analysis.
d) The advanced financial market infrastructure and technology would help markets to be more efficient.

e) The liquidity of the market is sufficient.

f) There are no legal barriers to information becoming public, and no insider trading laws.

However, in real world these assumptions also depend on transaction costs in the market, and market participants cannot get information without costs. That means that the transaction cost of the investors, information costs, and differences of opinion about the given information, are potential sources of inefficient markets.

Another problem is the market volume and liquidity. If low liquidity but high volume occurs in a transaction, a big crash of the stock market could occur. For instance, Black Monday (19.10.1987) in the American stock markets is a typical example markets need to have sufficient liquidity. But the EMH states that regardless of the existence of liquidity, the price is always fair, or assumes there is always sufficient liquidity. The EMH cannot explain stock market crashes or booms in markets. When liquidity disappears, completing the transaction is more important than getting a fair price.

There is a difference between a stable market and an efficient market in EMH. A stable market has high liquidity in the market. If the market is full of liquidity, we can think the price will be close to fair. However, the market can't be always full of liquidity. So when liquidity suddenly drops, investors will accept a high price in trading, regardless of the fair price. At this time, in order to obtain the liquid, traders bear the high cost.

According to the theory of behavioural finance, the efficient market hypothesis has two assumptions about investor behaviours: one is that the investors' behaviour is no different when attempting to maximize the value of their portfolios. Second is that the investors always tend to maximize their self-interests.

Behavioural finance theory argues that the EMH doesn't guarantee these two assumptions. On the other hand, according to the analysis of the actual situation, behavioural finance addresses the question of the rationality of these assumptions. Situations in which the investors violate these two assumptions will always appear, because of the influence of the emotional and psychological causes.

3.5 Characteristics of Efficient Market

The aim of this subchapter is to describe four basic characteristics of an efficient market. Reactions to new information, random changes in quotations, long-term returns on efficient markets, and business strategies in efficient markets, will be specifically introduced. Many economists, like DeBondt and Thaler (1985), Bernard and Thomas (1990), Chan (1988), Lo and MacKinlay (1988), etc., have already offered comprehensive explanations of these characteristics of an efficient market.

3.5.1 Reaction on New Information

No one can get excess returns when investors are investing in a random mode. This only guarantees an efficient market. In an efficient market, investors' behaviour is not rational, because investors have different reactions to new information.

An explanation for diversion from the EMH is that investors do not always react in proper way to new information. In some cases, stocks have recent losses or have recent gains, so investors can overreact by selling or buying the stocks. If investors are not rational, these overreactions will to push stock prices beyond their fair market value. This means that investors only focus on recent information, and ignore the previous information. When investors understand actual meaning of an event, they will bring prices back in line eventually.

In this case, investors can get excess returns. Since prices reverse, the stock price that goes up must come down, and vice versa. According to the contrarian investment strategies, losers are purchased and winners are sold.

For example, according to the monthly returns of New York Stock Exchange stocks during 1926 to 1982, DeBondt and Thaler (1985) documented the fact that the winners and losers in one 36-month period tend to reverse their behaviour over the next 36-month period. It is strange that many of these reversals occured in January. This confirms the anomaly of the January effect, which will be explained in subchapter 3.5.5.

In a long term, some irrational behaviour will probably appear in the market. If this behaviour is unpredictable, an economic crisis may occur. An economic bubble or a great depression may happen.

Bernard and Thomas (1990) found that investors sometimes underreact to new information about future earnings contained in current earnings.

There are many effects that are troubling for the EMH. According to Chan (1988), people can get excess return from contrarian investment strategies, but this does not prove that the EMH is not correct.

Moreover, Lo and MacKinlay (1988) demonstrated that at least half of the profits are not due to overreaction, so there is not sufficient evidence to conclude the failure of EMH.

3.5.2 Random Changes in Quotations

In the efficient market, there will be a lot of people looking for clues at any time, and they use those clues to make predictions about stock prices. Investors use any useful information for analysis, trying to sell at a high price and buy at a low price, because they don't want to give up any opportunity to make a profit in the market.

In fact, there are many investors taking part in this process at same time, so the changes in the stock price are quick. That is to say, when people use acquired information to predict the stock price, actually it is already too late. In the unpredictable market, the quotations will change without fixed scope.

Random walk hypotheses (RWH) plays an important role in description of random changes in quotations. It means that stock market prices evolve according to a random walk, and thus cannot be predicted.

RWH is a sufficient but not necessary condition for EMH. If RWH holds, EMH holds. But even if EMH holds perfectly, RWH could be violated.

For example, it is widely accepted that the risk premium depends on macroeconomic conditions. So good economic conditions predicts lower returns, but bad economic conditions predict higher returns. In this case, a market can be efficient, but the market can be predictable, so RWH be violated.

The first tests of the RWH were developed by Cowles and Jones (1937). They compared the frequency of sequences and reversals in historical stock returns. Then Cootner (1962; 1964), Fama (1963; 1965a), Fama and Blume (1966), and Osborne (1959) performed the tests of the RWH.

Malkiel (1973) performed a test in which his students were given a hypothetical stock that was worth fifty dollars at the beginning. Every day closing stock price was determined by a coin flip. If the coin was heads, the price would close a half point higher, but if the coin was tails, the price would close a half point lower.

So the price had a fifty-fifty chance that the closing price would be higher or lower than the previous day. There are not situations in which history tends to repeat itself. Malkiel thought that this indicates that the market and stocks could be just as random as flipping a coin. Moreover, the coin flips were random, the stock had no specific trend. If a stock increase in one day, stock market participant could not accurately predict that it would increase in next day.

In the test, if the market has the weak-form of efficiency, the change of stock price is subject to RWH. This will be further explained in the subchapter 3.6.2.

3.5.3 Long-term Returns on Efficient Markets

Since the market is random, time can be ignored. Under the framework of EMH, there is no relationship between current and past prices, or future and current prices. Moreover, regardless of the time variable, the price changes are random. But in fact, the time factor is actually very important.

For example, the price changes may not be random, because of overreaction from irrational investors in the short-term. But in the long-term, rational investors will correct the stock price. No investor can achieve above-average revenues at a given level of risk in the long term.

One of the first papers on long-term return anomalies was published by DeBondt and Thaler (1985). They find that when stocks are ranked on 3 to 5 year past returns, past winners tend to be future losers, and vice versa.

If apparent overreaction was the general result in studies of long-term returns, market efficiency would be dead, and must be replaced by the behavioural alternative of DeBondt and Thaler (1985). In fact, the apparent underreaction is frequent not the apparent overreaction. For example, in the momentum effect identified by Jegadeesh and Titman (1993), stocks with high returns over the past year tend to have high returns over the following three to six months.

3.5.4 Business Strategies on Efficient Markets

In efficient markets, business strategies do not work. On the basis of the efficient market hypothesis, the market is described as a result of rational economic agent, therefore there are no mistakes, or no irrational behaviour.

Arbitrage is the main business strategy on financial markets. However, if the efficient market hypothesis is hold, arbitrage is different. Arbitrageurs' behaviours can't make financial markets deviate from their basic value. In other words, the market mechanism can always quickly correct any mistakes.

Some individual investors, due to lack of professional investment knowledge, may sometimes overreact. But these mistakes will offset each other, and apparent under reaction will be about as frequent as overreaction. Therefore, the investors cannot acquire excess returns from any strategies in efficient markets.

For example, noise traders think that the stock prices are bullish. In an efficient market, anyone can obtain information, so arbitrageurs cannot sell the securities at higher price.

In the real world, economists find that noise trading is not practiced widely, but its influence on financial markets is significant. Therefore, it has created a huge impact on the mainstream position of the efficient market hypothesis.

In noise trading theory, noise will exist for a long time, due to information asymmetry and the long-term existence of the financial market uncertainty. The price may deviate from the basic value in long-term. There are many causes of noise, but one of the main causes is serious information asymmetry in financial markets and the different risk preference of traders.

3.5.5 Anomalies and Market Efficiency

Anomalies are the most common challenge to the EMH in long-term history. For example, one of the largest anomalies is the size effect. This refers to the relationship between stock yields and the size of the company. Banz was the first economist to discover the size effect. In 1981, he found that in the United States, total returns, or risk adjusted returns, were negatively related to the company's size. After Banz, other economists have done extensive testing on other major markets of developed countries, including Belgium, Canada, Japan, Spain, France, etc., they found that other countries have the size effect as well.

The other anomalies are the January effect and seasonal effect. These refer to the relationship between stock yields and the time. Rozeff and Kinney found that between 1904 and 1974, the yields of stock price indexes in January were significantly higher than the yields of the other 11 months in the New York Stock Exchange. And in 1983, Gultekin studied the stock yield of 17 countries from 1959 to 1979, and found that 13 countries' stocks' yield in January were higher than in other months.

Speculative investors can take advantage of these anomalies and get the excess returns. Under the EMH, it is not possible to happen the regularity of these stock returns, so economists have questioned the rational investors assumption.

Behavioural economics thinks that long-term anomalies are not the accidental events, but the EMH argues that the existence of the long-term anomalies is closely related to the measurement method. When the model changes, or uses different statistical methods, long-term anomalies may disappear, so the anomalies can still be classified as accidents.

In fact, luck can play another role in the explanation of anomalies in the real world, although the probability of finding such wrong regularities is usually small, especially if the regularity is a very complex pattern.

3.6 Models of Efficient Markets

This subchapter will introduce some models of efficient markets, including the martingale, fair game model and random walk models. Some definitions and explanations of models of efficient markets were introduced briefly by Bachelier (1900), Lucas (1978) and Campbell (1996).

3.6.1 Martingale and Fair Game Model

The martingale model originates from the history of games of chance and the birth of probability theory. A martingale is a sequence of random variables at a particular time. The expectation of the next value in the sequence is equal to the present observed value, that given knowledge of all prior observed values.

There are various versions of martingale and random walk models. They consider the various kinds of dependence that can exist between an asset's returns r_t and r_{t+k} at two dates t and $t+k$.

We define the random variables $f(r_t)$ and $g(r_{t+k})$, where $f(\cdot)$ and $g(\cdot)$ are two arbitrary functions. The covariance formula can be wrote as:

$$\mathrm{Cov}[f(r_t), \mathrm{g}(r_{t+k})] = 0. \tag{3.1}$$

In this equation, all t and for $k \neq 0$. According to equation (3.1), $f(\cdot)$ is unrestricted but $\mathrm{g}(\cdot)$ is restricted to be liner in the martingale hypothesis.

This refers to a fair game which neither favours you nor your opponent, and this is the basis of a martingale. It is a stochastic process $\{P_t\}$ which meets the conditions:

$$\mathrm{E}[P_{t+1}|P_t, P_{t-1}, \dots \dots] = P_t, \tag{3.2}$$

or, equivalently,

$$\mathrm{E}[P_{t+1} - P_t|P_t, P_{t-1}, \dots \dots] = 0, \tag{3.3}$$

When conditioned on the history of the game, in equation (3.2), if P_t shows one's accumulated wins at time t from playing some game of chance each period, then a fair game is one for which the expected wins next period are simply equal to this period's wins. At the same time, in equation (3.3), if the expected incremental wins at any stage is zero, it is also a fair game.

3.6.2 Random Walk Models

There can be defined three different types of random walk models. The random walk 1 model (RW1) assumes the independently and identically distributed (IID) increments, while the random walk 2 model (RW2) is independent increments and in the case of the random walk 3 model (RW3) are expected uncorrelated increments.

If $f(\cdot)$ and $\mathrm{g}(\cdot)$ as defined by equation (3.1) are restricted to be arbitrary linear functions, then it implies that returns are serially uncorrelated. This corresponds to the random walk 3 model. If all functions $f(\cdot)$ and $\mathrm{g}(\cdot)$ in equation (3.1) are unrestricted, this implies that returns are mutually independent, corresponding to the random walk 1 and random walk 2 models.

In the random walk 1, $\{P_t\}$ are given by this equation:

$$P_t = \mu + P_{t-1} + \epsilon_t, \ \epsilon_t \sim IID(o, \sigma^2), \tag{3.4}$$

where μ is the expected price change, and $IID(o, \sigma^2)$ indicates that ϵ_t is independently and identically distributed with a mean of 0 and a variance of σ^2. The independence of the increments ϵ_t shows that the random walk is also a fair game. Also important the fact is that independence shows not only that the increments are uncorrelated, but that any nonlinear functions of the increments are also uncorrelated. When we know the initial value P_0 at date 0, the conditional mean and variance at date *t* is:

$$E[P_t | P_0] = P_0 + \mu t, \tag{3.5}$$

$$Var[P_t | P_0] = \sigma^2 t. \tag{3.6}$$

Equations (3.5) and (3.6), show that the random walk is nonstationary process. At the same time, the conditional mean and variance are both linear. It also holds for the RW2 and RW3.

In the random walk 2 model, we extend the assumptions of the random walk 1 to include processes with independent but not identically distributed increments, because the assumption of identically distributed increments is not reasonable for stock prices over the long term. For example, in the New York Stock Exchange, there were many changes in social, technological, economic and other factors over the last two hundred years. Hence, it is not reasonable that the daily stock returns have remained the same over two hundred years.

Therefore the random walk 2 model is weaker than the random walk 1. Moreover, random walk 2 model allows for unconditional heteroscedasticity in the ϵ_t. However, any transformation of future price increments is unpredictable using any transformation of past price increments.

The random walk 3 is the weakest form of random walk hypothesis. It extends the independence assumption of RW2 to include processes with dependent but uncorrelated increments when $\text{Cov}[\epsilon_t, \epsilon_{t-k}] = 0$ for all $k \neq 0$, but where $\text{Cov}[\epsilon_t^2, \epsilon_{t-k}^2] \neq 0$ for some $k \neq 0$. This process satisfies the assumptions of RW3 but not of RW1 and RW2. Therefore, the process has uncorrelated increments, if its squared increments are correlated. So it is not independent.

Table 3.1 shows the classification of random walk 1, 2, 3 models and martingale process.

Table 3.1. Classification of random walk and martingale hypotheses.

$\mathrm{Cov}[f(r_t), \mathrm{g}(r_{t+k})] = 0$	$\mathrm{g}(r_{t+k}), \forall \mathrm{g}(\cdot)$ Linear	$\mathrm{g}(r_{t+k}), \forall \mathrm{g}(\cdot)$
$f(r_t), \forall f(\cdot)$ Linear	Uncorrelated Increments, Random walk 3: $\mathrm{Proj}[r_{t+k} \vert r_t] = \mu$	
$f(r_t), \forall f(\cdot)$	Martingale/Fair Game: $\mathrm{E}[r_{t+k} \vert r_t] = \mu$	Independent Increments, Random walks 1 and 2: $\mathrm{pdf}[r_{t+k} \vert r_t] = \mathrm{pdf}(r_{t+k})$

Source: CAMPBELL (1997)

$\mathrm{Proj}[y|x]$ means the linear projection of y onto x, and $\mathrm{pdf}[y|x]$ means the probability density function of its argument.

3.6.3 Studies on Testing the Weak Form of Efficient Market Hypothesis

Over the past decade, many empirical studies have focused on the weak form of efficient market hypothesis. We know that in weak form of efficient market, stock prices reflect information such as past prices and trading volume.

Fama (1965) provided an empirical analysis of runs for US stock market. He used daily, four-days, nine-days, and sixteen-days stock returns from 1956 to 1962, and concluded that *"there is no evidence of important dependence from either an investment or a statistical point view"*.

Cooper (1982) studied world stock markets using monthly, weekly and daily data for 36 countries. He examined the validity of the random walk hypothesis by using correlation analysis, run tests and spectral analysis.

De Bondt and Thaler (1985) discovered that the stock prices overreacted, evidencing substantial weak form market inefficiencies. Black (1986) described the concept of noise traders, and explained that noise trading is essential to the existence of liquid markets.

French and Roll (1986) emphasized that stock prices are much more volatile during exchange trading hours than during non-trading hours. They deduced the market generates its own news.

Lo and Mackinlay (1988) rejected the random walk hypothesis for weekly stock market returns using the variance-ratio test. At the same time, Poterba and Summers (1988) introduced that stock returns show positive autocorrelation during short periods and negative autocorrelation during longer horizons.

Laffont and Maskin (1990) found that the efficient market hypothesis could fail if there is imperfect competition. Haugen (1995) concluded that short-run overreaction may lead to long-term reversals. Since the market recognized its past errors.

Harvey (1995) examined more than 800 stock returns from twenty emerging economies and reported that the degree of predictability in the emerging markets is greater than the developed markets.

In China, empirical studies of Song and Jin (1995) determined that the Shanghai Stock Exchange has already been weakly efficient or come close to the weak form of efficiency. However, Zhang and Zhou (2001) showed that China's stock market has not achieved weak-form of efficiency.

Cooray (2003) tested the random walk hypothesis for Japan and Hong Kong markets by unit root tests. This study was used monthly data and the results were that there exhibit a random walk.

Whorthingthon and Higgs (2006) examined for random walks daily returns in Asia. They used the runs tests, variance ratio tests and so on. The results from variance ratio tests indicated China doesn't follow weak form of efficient market. However, Hong Kong and Japan were consistent with the random walk criteria.

In Europe, Andrew and Helen (2010) tested the weak form efficiency of twenty European markets by the root tests. In UK, they rejected the random walk in daily returns.

4. Methods for Testing Information Efficiency

Chapter 4 will explain some important methods for testing the weak form of information efficiency as defined by Lo and MacKinlay (1988, 1989), Mood (1940), White (1980) and Brock, Dechert, Scheinkman, LeBaron (1996) and Campbell (1996).

Firstly, we will describe the statistical tests, which includes linear methods and nonlinear methods to test the weak form of efficiency. The second aspect we will introduce features of financial time series. Moreover, we will find some possible problems of testing efficiency from microstructure of financial markets.

4.1 Statistical Tests

With reference to Lo and MacKinlay (1988), White (1980) and Brock, Dechert, Scheinkman and LeBaron (1996), the contents of Subchapter 4.1 will lead us to a quick view of linear and nonlinear methods. These methods will be applied in chapter 5.

The linear methods include three tests: the variance ratio test, the Ljung-Box test and the runs test. Similarly, the nonlinear methods also include three tests: the White test, the Engle´s test and the BDS test. We will use these methods to test our selected stock exchange markets indexes whether they satisfy the weak form of efficiency.

4.1.1 Testing the Weak Form of Efficiency by Linear Methods

In this subchapter, we will describe three methods which used for testing the weak form of efficiency by linear methods.

a) Variance Ratio Test

The Variance ratio test was proposed by Lo and MacKinlay (1988, 1989). They examined the predictability of time series data by comparing the variances of differences of the data during different time intervals. If we assume the prices follow a random walk, then the variance of their q^{th} difference will increase proportionally to q.

Evaluating the empirical evidence for or against this restriction is the basis of the variance ratio test.

In the first step of the test procedure, we assume the time series $\{P_t\} = (P_0, P_1, P_2, \dots, P_T)$ satisfying:

$$\Delta P_t = \mu + \epsilon_t, \tag{4.1}$$

where μ is an arbitrary drift parameter. The key contents of a random walk that we would like to test are $E(\epsilon_t) = 0$ for all *t* and $E(\epsilon_t \epsilon_{t-j}) = 0$ for any positive j.

Then we can make the strong assumption that ϵ_t is independently and identically distributed with $E(\epsilon_t) = 0$ and $var(\epsilon_t) = \sigma^2$ (RW1). Therefore, this is a homoscedastic random walk hypothesis.

We can define estimators for the mean of first difference and the scaled variance of the q^{th} difference:

$$\hat{\mu} = \frac{1}{T}\sum_{t=1}^{T}(P_t - P_{t-1}), \tag{4.2}$$

$$\hat{\sigma}^2(q) = \frac{1}{Tq}\sum_{t=1}^{T}(P_t - P_{t-q} - q\hat{\mu})^2, \tag{4.3}$$

and the corresponding variance ratio is:

$$VR(q) = \hat{\sigma}^2(q)/\hat{\sigma}^2(1). \tag{4.4}$$

Lo and MacKinlay (1988, 1989) replace *P* in equation (4.2) and (4.3) with (*P*-*q*+1) in the no-drift case, or with (*P*-*q*+1) (1-*q*/*P*) in the drift case. Therefore, the variance estimators may be adjusted for bias.

Lo and MacKinlay (1988, 1989) showed that the variance ratio z-statistic is asymptotically *N*(0,1) for the appropriate choice of estimator $\hat{s}^2(q)$. The formula of z-statistic is:

$$\mathrm{z(q)} = (\mathrm{VR(q)} - 1) \cdot [\hat{s}^2(q)]^{-1/2}. \tag{4.5}$$

Under RW1 hypothesis we have the estimator,

$$\hat{s}^2(q) = \frac{2(2q-1)(q-1)}{3qP}. \tag{4.6}$$

Alternately, Lo and MacKinlay (1988, 1989) weaken the *IID* assumption and allow for fairly general forms of conditional heteroscedasticity and dependence. This is a heteroscedastic random walk hypothesis (RW2). Conditions for ϵ_t to be a martingale difference sequence. The variance ratio test will be applied to verify the EMH in the form of martingale process in this thesis.

Under this assumption, we can use the kernel estimator:

$$\hat{s}^2(q) = \sum_{j=1}^{q-1} (\frac{2(q-j)}{q})^2 \cdot \hat{\delta}_j, \tag{4.7}$$

where

$$\hat{\delta}_j = \left\{ \sum_{t=j+1}^{T} \left(p_{t-j} - \mu^2\right)^2 (p_t - \mu^2)^2 \right\} / \left\{ \sum_{t=j+1}^{T} \left(p_{t-j} - \mu^2\right)^2 \right\}^2 . \tag{4.8}$$

b) Ljung-Box Test

The Ljung-Box test is not as powerful as the variance ratio test. However, it is easy to perform. The definition and some explanations of this test by Ljung and Box (1979). This statistical test evaluates whether any of a group of autocorrelations of a time series are different from zero. It tests the overall randomness based on a number of lags rather than testing randomness at each distinct lag. Therefore, it is a portmanteau test.

We assume H_0: The data are independently distributed.

The *Q*-statistic at lag *k* is a test statistic for the null hypothesis that there is no autocorrelation up to order *k*. This formula is calculated as:

$$Q_{LB} = T(T+2) \sum_{j=1}^{k} \frac{r_j^2}{T-j} , \tag{4.9}$$

where r_j is the *j*th autocorrelation and *T* is the number of observations.

Under H_0 the statistic Q follows a $\chi^2_{(k)}$. For significance level α, the critical region for rejection of the hypothesis is: $Q > \chi^2_{1-\alpha,k}$, where $\chi^2_{1-\alpha,k}$ is the α-quantile of the chi-squared distribution with *k* degrees of freedom.

c) Runs Test

Another common linear test is the runs test. Mood (1940) was the first who provided the analysis of runs. According to the equation (3.4), we use I_t to represent the following random variable:

$$I_t = \begin{cases} 1 \text{ if } r_t \equiv p_t - p_{t-1} > 0 \\ 0 \text{ if } r_t \equiv p_t - p_{t-1} \leq 0 \end{cases} , \tag{4.10}$$

where I_t indicates whether continuously compounded return r_t is positive or negative. For example, we can use equation (4.10) to calculate a particular sequence of 10 returns. This results may be represented by 1001110010, including three runs of 1s (of lengths 1, 3, and 1, respectively) and three runs of 0s (of lengths 2, 2, and 1, respectively). In total, there are six runs.

Under RW1 (CAMPBELL, 1997), we suppose the sampling distribution of the total number of runs N_{runs} in a sample of n. Each of n observations takes on one of q possible values with probability $\pi_i, i = 1, \ldots, q$ (hence $\sum_i \pi_i = 1$). According to the equation (4.10), we know that q is equal to 2, therefore, $n_1 + n_2 = n$. We use $N_{runs}(i)$ to represent the total number of runs of type i (of any length).

In this test, the formula of Fama (1965) is:

$$\mathrm{E}[N_{runs}(i)] = \frac{2n_1 n_2}{n} + 1, \tag{4.11}$$

$$\mathrm{Var}[N_{runs}(i)] = \left[\frac{2n_1 n_2(2n_1 n_2 - n)}{n^2(n-1)}\right]. \tag{4.12}$$

In a large sample, it has approximately normal distribution:

$$\mathrm{Z} = \frac{N_{runs} - \mathrm{E}[N_{runs}(i)]}{\sigma[N_{runs}(i)]} \sim N(0,1). \tag{4.13}$$

If $|Z|$ is located in the critical region at significance level α, it means that observations have a potential trend.

Mood (1940) derives the discrete distribution of $N_{runs}(i)$, from which he calculates the following formula:

$$\mathrm{E}[N_{runs}(i)] = \frac{2n_1 n_2}{n} + \frac{n_1^2 + n_2^2}{n^2}, \tag{4.14}$$

$$\mathrm{E}[N_{runs}(i)] \in \left[\frac{2n_1 n_2}{n} + \frac{1}{2}, \frac{2n_1 n_2}{n} + 1\right], \tag{4.15}$$

$$\mathrm{Var}[N_{runs}(i)] = \frac{4n_1 n_2(n_1^2 + n_2^2 - n_1 n_2)}{n^3}. \tag{4.16}$$

When the difference of n_1 and n_2 is big, the results of Mood and Fama tests will have some differences.

4.1.2 Testing the Weak Form of Efficiency by Nonlinear Methods

Next, we will introduce the nonlinear methods to test the weak form of efficiency.

a) White Test

This test was defined by White (1980) and it is used to test the null hypothesis of no heteroscedasticity against alternative heteroscedasticity of test. The statistic is calculated by the auxiliary regression, where we regress the squared residuals on all possible (nonredundant) cross products of the regressors. Therefore, we assume to estimate estimated following regression:

$$y_t = b_1 + b_2 x_t + b_3 z_t + e_t, \tag{4.17}$$

where e is residual term and b_1, b_2 and b_3 are the estimated parameters. The value of statistic test based on the auxiliary regression:

$$e_t^2 = \alpha_0 + \alpha_1 x_t + \alpha_2 z_t + \alpha_3 x_t^2 + \alpha_4 z_t^2 + \alpha_5 x_t z_t + v_t. \tag{4.18}$$

This test is a general test for model misspecification. Under the null hypothesis the test assumes that the errors are both homoscedastic and independent, and that the linear specification of the model is correct. If any one of these conditions failed, it will lead to a significant test statistic. On the contrary, a non-significant test statistic implies that none of the three conditions is violated.

b) Engle´s Test

ARCH models were firstly introduced by Engle (1982) and then were developed as GARCH (Generalized ARCH) by Bollerslev (1986) and Taylor (1986). Autoregressive Conditional Heteroscedasticity (ARCH) model is technically designed to forecast conditional variances. The variance of the dependent variable is modeled as a function of past values, or exogenous variables.

The mean equation given in (4.19) is a function of exogenous variables with an error term of GARCH (1, 1):

$$Y_t = X_t'\theta + \epsilon_t, \tag{4.19}$$

$$\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2, \tag{4.20}$$

where σ_t^2 is the conditional variance. It means the one-period ahead forecast of variance is based on past information. The ω is a constant term, ϵ_{t-1}^2 (the ARCH term) is measured as the lag of the squared residual from the mean equation, and σ_{t-1}^2 (the GARCH term) is the last period's forecast variance.

Next, higher order GARCH models is GARCH (*q*, *p*). It can be estimated by choosing either q or p greater than 1. Therefore, q is the order of the autoregressive GARCH terms and p is the order of the moving average ARCH terms.

The formula of the GARCH (q, p) variance is:

$$\sigma_t^2 = \omega + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 + \sum_{i=1}^{p} \alpha_i \epsilon_{t-i}^2. \tag{4.21}$$

c) BDS Test

The BDS test for independence was firstly described by Brock, Dechert, Scheinkman and LeBaron (1996). We can use this test to check whether the residuals are independent and identically distributed in a series of estimated residuals.

The BDS test is a portmanteau test for time based dependence in a series. It can also test a lot of possible deviations from independence including non-linear dependence or chaos.

In this test, we have to choose a distance and consider a pair of points. If the observations are independent and identical, the probability of the distance between these points being less than or equal to ϵ will be constant for any pair of points. This probability be denoted by $c_1(\epsilon)$.

Therefore, we can also constitute multiple pairs of points. We assume an observation *s,* and an observation *t* of a series *X*, thus the form of a set of pairs is:

$$\{\{X_s, X_t\}, \{X_{s+1}, X_{t+1}\}, \{X_{s+2}, X_{t+2}\}, \dots, \{X_{s+m-1}, X_{t+m-1}\}\} \tag{4.22}$$

where m is the number of consecutive points used in the set. The joint probability $c_m(\epsilon)$ of every pair of points satisfies the ϵ condition.

Under the assumption of independence, this probability will be a product of individual probabilities for each pair. If the observations are independent,

$$c_m(\epsilon) = c_1^m(\epsilon). \tag{4.23}$$

When using this test, we do not directly observe $c_1(\epsilon)$ or $c_m(\epsilon)$, we can only estimate them from the sample data. Then, we do not hold this relationship exactly, but only with some error. If the error is larger, the possible is less of the error which is caused by random sample variation. As a result, the BDS test can judge the size of this error.

To estimate the probability, we can use the ratio of the number of sets satisfying the condition divided by the total number of sets. In addition to this, given a sample of *n* observations of a series *X*. We can use this mathematical notation to describe this condition, and the statistics $c_{m,n}$ are referred to as correlation integrals:

$$c_{m,n}(\epsilon) = \frac{2}{(n-m+1)(n-m)} \sum_{s=1}^{n-m+1} \sum_{t=s+1}^{n-m+1} \prod_{j=0}^{m-1} I_\epsilon\left(X_{s+j}, X_{t+j}\right), \tag{4.24}$$

where I_ϵ is the indicator function:

$$I_\epsilon(\mathrm{x},\mathrm{y}) = \begin{cases} 1 & if|x-y| \le \epsilon \\ 0 & \text{otherwise.} \end{cases} \tag{4.25}$$

Then we can construct a test statistic for independence through these estimates of the probabilities:

$$b_{m,n}(\epsilon) = c_{m,n}(\epsilon) - c_{1,n-m+1}(\epsilon)^m, \tag{4.26}$$

where the second term discards the last *m-1* observations from the sample so that it is based on the same number of terms as the first statistic.

According to the assumption of independence, we could expect this statistic to be close to zero. The formula is shown in Brock et al. (1996):

$$(\sqrt{n-m+1}\frac{b_{m,n}(\epsilon)}{\sigma_{m,n}(\epsilon)} \to N(0,1), \tag{4.27}$$

where

$$\sigma_{m,n}^2(\epsilon) = 4\left(k^m + 2\sum_{j=1}^{m-1} k^{m-j} c_1^{2j} + (m-1)^2 c_1^{2m} - m^2 k c_1^{2m-2}\right), \tag{4.28}$$

and where c_1 can be estimated using $c_{1,n}$. k is the probability of any triplet of points lying within ϵ of each other, and is estimated by counting the number of sets satisfying the sample condition:

$$k_n(\epsilon) = \frac{2}{n(n-1)(n-2)} \sum_{t=1}^{n} \sum_{s=t+1}^{n} \sum_{r=s+1}^{n}, \tag{4.29}$$

$$(I_\epsilon(X_t, X_s) I_\epsilon(X_s, X_T) + I_\epsilon(X_t, X_T) I_\epsilon(X_T, X_s) + I_\epsilon(X_s, X_t) I_\epsilon(X_t, X_T). \tag{4.30}$$

4.2 Features of Financial Time Series and Possible Problems of Testing Efficiency

This subchapter will describe typical features of financial time series. The linear analysis is the most frequent application in financial time series. To analyze financial time series correctly, we should consider some assumptions.

In particular, there will be emphasize assumptions of normality and linearity. Another aspect that should be discussed is related to microstructure of financial markets.

4.2.1 Assumption of normality

The first assumption can be called normality, which is the precondition for constructing point forecasts and interpreting the estimated parameters.

We know the most used distribution in statistical analysis is the normal distribution, sometimes called the Gaussian distribution. In this assumption, it means the residual term is distributed normally. Therefore, the residual are defined by the following function:

$$\epsilon_t = p_t - \hat{p}_t, \tag{4.31}$$

where p_t is the value of the time series or the dependent variable at time t, and $\hat{p}_t$ is the predicated value of y. In addition, this assumption can break down when there are multiple sources of residuals and they are correlated.

If the residuals term are not truly random, then this assumption must be failed. If we expect normality, but residual distribution is not normal, then there could lead to an incorrect statistical analysis and wrong conclusions. When testing the efficiency of the market, we have to check whether the residuals term is random.

There exist some statistical tests to test the normality of variables. These tests are based on estimation of skewness, kurtosis, and normal probability plot. However, the statistics to assess that it is unstable in small samples.

For instance, the Jarque-Bera (JB) statistic also can used to test whether the series is normally distributed. The test statistic measures the difference of the skewness and kurtosis of the series with those from the normal distribution. The formula of this statistic can be presented as:

$$\mathrm{JB} = \frac{6}{N}\left(S^2 + \frac{(K-3)^2}{4}\right), \tag{4.32}$$

where S is the skewness, and K is the kurtosis. Under the null hypothesis of a normal distribution, the Jarque-Bera statistic is distributed as χ^2 with 2 degrees of freedom

4.2.2 Assumption of linearity

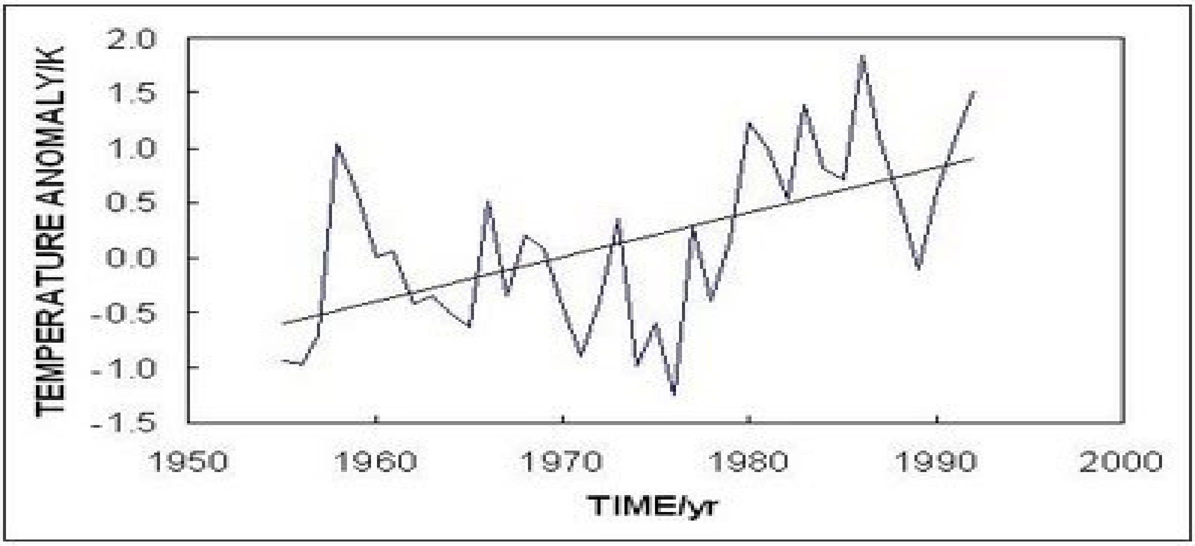
Under this assumption, there is linearity between the dependent variables and independent variables. This relationship at time *t* can be defined by the following formula:

$$p_t = \beta_0 + \beta_1 \cdot t + \epsilon_t, \tag{4.33}$$

where β_0 is the coefficient of constant, β_1 is the slope coefficient, and ϵ_t is residual term.

Figure 4.1 presents the example of linear time series model.

Figure 4.1: Linear time series model



Source: Rabett (2010)

For instance, the formula of non-linearity time series model can be presented as:

$$y_t = e^{\beta_0 + \beta_1 \cdot t} + \epsilon_t. \tag{4.34}$$

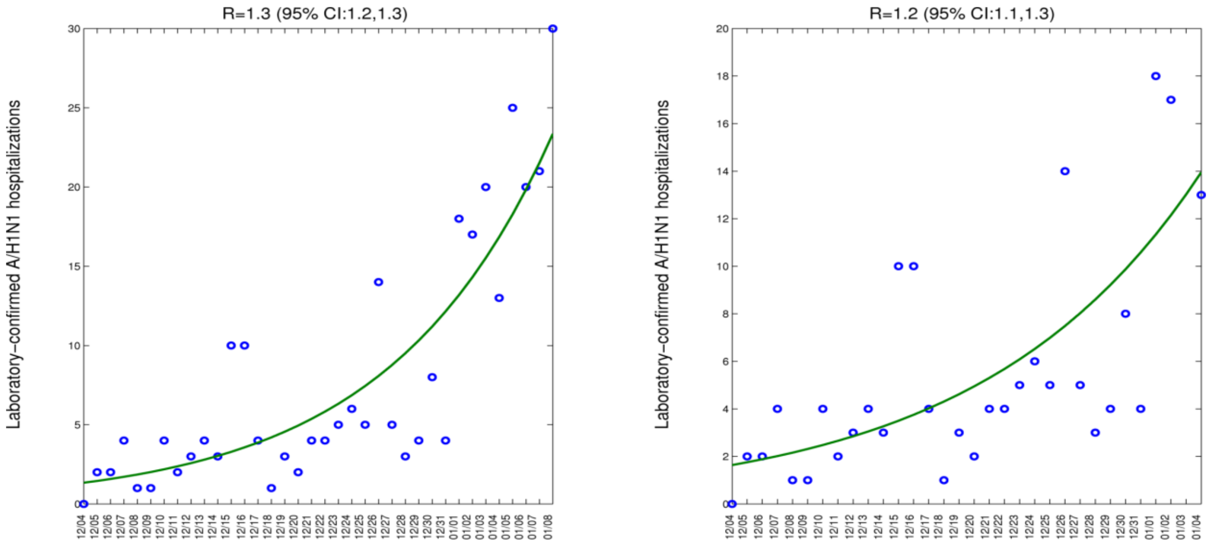
To estimate (4.33), we can use ordinary least squares (OLS) to estimate the unknown parameters in a linear regression model. The aim of this method is to minimize the differences between the observations and estimated linear function.

The difference between linear and non-linear time series model can be demonstrated by Figure 4.1 and Figure 4.2.

The Figure 4.2 is presented the example of non-linearity time series model.

To sum up, the assumption of linearity in financial time series models is too strong. Empirical behavior of financial time series can also show sighs of nonlinear dependency. This fact will be considered when testing the EMH in Chapter 5.

Figure 4.2 Non-linearity time series model



Source: Catherine Mulbrandon (2010)

4.2.3 Microstructure of Financial Markets

The microstructure of financial markets mainly examines the ways in which the working processes of a market affects determinants of transaction costs, prices, quotes, volume, and trading behavior (CAMPBELL, 1997).

Therefore, we will discuss nonsynchronous trading, bid–ask spread, and price movements in this subchapter.

Nonsynchronous trading means that different stocks may have different trading frequencies. For example, the trading intensity of a single stock varies from hour to hour and from day to day. In general, for this purpose of this thesis, we assume daily returns as an equally spaced time series with a 24-hour interval.

Other effect of transaction in the real world is bid–ask spread. The market makers have very important role in the transaction market. They provide market liquidity by standing ready to buy or sell whenever the public wishes to buy or sell. Since they have an ability to buy or sell a great quantity of a security quickly, anonymously, and with little price impact. Therefore, they have significant rights to post different prices for purchases and sales of a security.

The market makers buy at the bid price P_b and sell at a higher ask price P_a. The public is inverse, they buy the security at the P_a and sell the security at the P_b. The difference between P_a and P_b $(P_a - P_b)$ is called the bid-ask spread, which is the compensation for market makers. Even though the bid-ask spread is very small, it also has several important consequences in time series properties of asset returns.

Next, the important term is the transaction data which includes some variables such as the transaction price, the transaction volume, the bid and ask quotes, and so on. These data have many important characteristics that do not exist when the observations are aggregated over time.

First characteristic is unequally Spaced Time Intervals. For example, trading on stock exchange do not occur at equally spaced time intervals. The time duration between transactions could contain useful information about market microstructure.

Next characteristic is an existence of periodic pattern. For instance, on Shanghai exchange market, there are many transactions at the beginning and closing of the trading hours, but there are less transaction during lunch hour. Therefore, time durations between transactions also exhibit a daily cyclical pattern.

In real world, these situations will become possible problems of testing efficiency.

5. Empirical Testing the Weak Form of Efficiency

Chapter 5 will deliver results of testing the weak form of efficiency of four stock markets using linear and nonlinear methods as defined in Chapter 4. Moreover, achieved results will be compared. Firstly we will introduce the all investigated stock markets.

All the Tables and Figures included in this subchapter are made by author with the help of Excel and EViews7.

5.1 Description of Investigated Stock Exchanges

The purposed stock exchange of our objects are Shanghai Stock Exchange, Hong Kong Stock Exchange, Tokyo Stock Exchange and London Stock Exchange. Since Shanghai, Hong Kong are both from China, it will be interesting to see institutional differences of both Chinese stock markets. Tokyo belongs to developed stock markets. Finally, it will be interesting to see the difference of behaviour of London stock markets which belongs to developed European markets.

In addition, we will choose one index from each stock exchanges as a proxy of each market.

5.1.1 Chinese Stock Exchanges

In China, there are four major stock exchanges. In particular, they are Shanghai Stock Exchange, Shenzhen Stock Exchange, Hong Kong Exchanges, and Taiwan Stock Exchange. In this thesis, we will focus on Shanghai and Hong Kong Exchanges.

The **Shanghai Stock Exchange** (SSE) was founded on Nov 26th, 1990 and it is in operation from Dec 19th of the same year. Moreover, it is first exchange market established in China. The main trading rules of *SSE* are:

(1) Trading time is from Monday to Friday, in the morning, 9:15 to 9:25 is when to call auction. Opening price depend on this time, and the stock's opening price is the first transaction price in this day. From 9:30 to 11:30 it is continuous bidding time. In the afternoon, from 13:00 to 15:00 it is continuous bidding time as well.

(2) In order to improve exchange's efficiency, exchange regulates every time the number of trading units and transactions. The number of tradings is usually a unit or the integer times of a unit and one unit is 100 shares. When investors has less than 100 shares, the whole package should be sold at once. The largest number of individual transaction is limited by 1 million shares.
(3) The Shanghai stock exchange is significantly different from Hong Kong and many other developed countries. It implements price limit for stock trading, and price ratio is 10% of this day. But there are several special circumstances, like the first day of trading with no price limit and so on.
(4) Stocks or funds in the Shanghai stock exchange, the trading system is dealt at time $T + 1$. That is to say, today you buy the stock or funds and you must sell the stock or funds in the next day.

In Shanghai Stock Exchange, the indexes can be divided into group of sample indexes and comprehensive indexes. In first group, there are three constituent stock indexes, namely Shanghai 180 index, Shanghai 50 index and Shanghai 380 index. For example, Shanghai 180 index has 180 stocks, every year adjust constituent stock, and the proportion of adjustment is no more than 10%.

Shanghai composite index is a representative of comprehensive index. For the first time, it was defined on 19.12.1990.

Hong Kong Exchange (HKEX).

HKEX has more perfect financial system compared to the Shanghai stock exchange. This market is less regulated and has more typical features for developed stock markets.
The main trading rules are:

(1) Trading unit is different compared to the Shanghai stock markets. One unit of the Hong Kong stock exchange is not fixed. The stock regulation is different. For instance, one unit can include 400 shares, 1000 shares, 2000 shares and 4000 shares.
(2) Compared to Shanghai stock exhange, there is $T + 0$ rotary deal in Hong Kong stock exchange, and there is no price limit. At the same time, the actual delivery time is the second working day after the trading day, so the HKEX applies $T + 2$ trading system. The

customer can not withdraw cash or shares and cannot do custody transfer of buying shares before the actual delivery time. In simple terms, the stock can be traded countless times in one day, but the investors will obtain money at the day after tomorrow.

The Hang Seng index is the most important index of the Hong Kong stock market. It was defined for the first time in 1964. This index contains 50 stocks of the Hong Kong stock market with different weights. The result is weighted average share price index that can reflect the trend of the Hong Kong stock market price range. So that it’s a kind of the most influential stock index.

5.1.2 Tokyo Stock Exchange

Tokyo Stock Exchanges is one of the world's largest stock exchange. It was established in 1878 and it had 2292 listed companies in 2015. The main characteristics are:

(1) For a long time, a large number of public savings have relied on financial institutions to invest, so the securities market is big. The fact that securities issuance market is narrow, it is only face to a little financial institutions. So the securities issuance markets of shares and bonds become abstract intangible market.

(2) The indirect investment is relatively developed. The stock market expanded rapidly, becoming the new financing channels. The trading unit also applies $T + 0$ in Tokyo stock exchange. Moreover, from 9:00 to 11:00 and 12:30 to 15:00 they are continuous bidding time.

(3) A large share of national debt is traded on the Tokyo stock exchange, and forms significant part of the whole market.

Nikkei Stock Average is the main index in Japan stock market. Nikkei 225 index is published for a long time, so that it has very good comparability. It became the most commonly used index and the most reliable indicator about the long-term evolution of stock market prices in Japan

.

5.1.3 London Stock Exchange

The London stock exchange will be compared with Asian stock markets in this paper, since it belongs to developed stock markets. It was founded in 1801, it is older than Asian stock market. The main characteristics of London stock exchange are:

(1) There are many types of listed securities, about fifty percent constitute foreign securities. It operates on four independent transaction markets.
(2) Trading time is different compared with Chinese and Japanese stock markets. It is from Monday to Friday. In the morning, from 8:30 to 9:30 in winter is when to call auction, and from 7:30 in summer. Opening price depends on this time, and the stock's opening price is the first transaction price in this day. From 9:30 to 15:00 is continuous bidding time. Therefore, there are no noon breaks.
(3) The trading unit is similar to Hong Kong stock market, as there is $T + 0$ rotary deal. Moreocer, it is dealt by automatically quoting price generated computer system. It is possible to compute and acquire stock prices at any time.

There are many important indexes in the London stock market, like FTSE 100 index, FTSE 250 index, FTSE Eurotop 100 index, FTSE SmallCap Index and so on. The FTSE 100 index includes 100 stocks that are listed on the London stock exchange and it has biggest market capitalisation. It is one of the world's most popular financial products to investors. Moreover, it has representativeness, and is an important index to reflect the actual changes of stock prices on the London stock market.

5.2 Data Sample Description

Data samples that are applied in this thesis come from the stock indexes of four stock exchange markets, namely Shanghai, Hong Kong, Tokyo and London. These markets have been described in subchapter 5.1. Main stock indexes are good indicators of the overall situation on investigated markets. We choose the Shanghai composite stock index, Hang Seng index, Nikkei 225 index and FTSE 100 index as representatives of the stock market. All the data which are used for the purpose of this thesis are downloaded from Yahoo Finance (http://finance.yahoo.com). We will apply daily closing prices.

The aim of this subchapter is to describe statisticaly the development of the indexes during the certain time and to compute basic descriptive statistics. For the purpose of this thesis, we choose the daily data from 01/01/2003 to 10/30/2015.

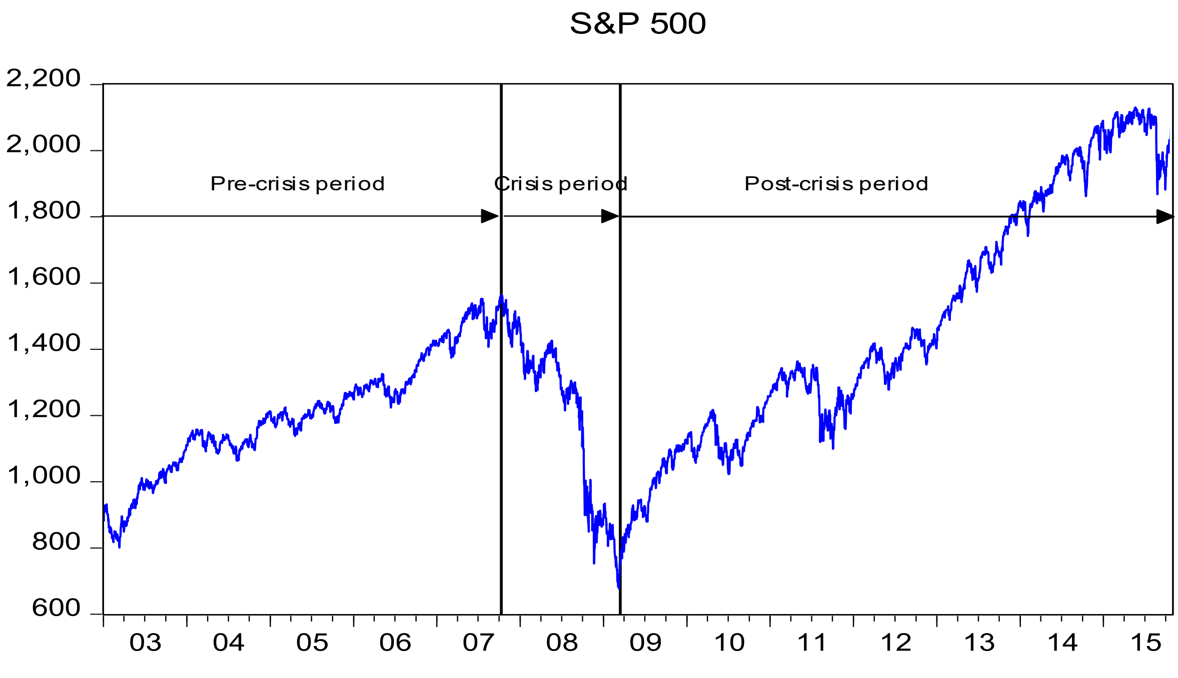
Moreover, we divided the sample data into three time sub periods. Sub periods have been defined on the basis of development of S&P 500 index. Since development and events on the US stock market may be considered a benchmark of global stock market.

In Figure 5.1, it can be seen the trend of S&P 500 index. Basic periods are divided into three sub-periods by two man-made lines. First period was defined from 01/01/2003 to 10/05/2007. There are 1739 observations, and we call it the pre-crisis period. In May of 2007, some subprime mortgage lender files for bankruptcy protection in America.

Then the second period is from 10/05/2007 till 03/09/2009, which is the period under the influence of global financial crisis. There are 522 observations. In September of 2009, Finance ministers from the world's most powerful economies have agreed a series of measures to try to regulate the global banking system. This sub period starts when the US stock market started to decline and ends when the US stock market reached its bottom.

The third period will start from 03/09/2009 till 10/30/2015, and there are 2427 observations. This period is after the crisis and we call it the post-crisis period.

Figure 5.1: Daily closing pieces of S&P 500 index



Source: own calculation in Eviews

No financial institution (like the World Bank) or specialised financial authority indicate exactly the duration of global financial crisis. That is why we decided to define all sub periods on the basis of development of S&P 500 index that is a proxy of US stock market.

5.2.1 Data Sample from China

As it has been mentioned in subchapter 5.1.1, Shanghai stock exchange is important exchange market in China. The Shanghai composite stock index can be used as a benchmark to reflect the whole economic situation of China. On the other hand, Hong Kong is more perfect and with less regulation than Shanghai stock market. Therefore, Hang Seng index is more important in the world economy and also can reflect the economic situation of China in some way.

With the help of Eviews 7, we can plot the large sum of data into line chart to form a basic trends of Shanghai composite stock index and Hang Seng index as well.

The Figure 5.2 shows daily closing prices of Shanghai composite index during the given testing period. We have already divided the daily data into three time periods that have been described in subchapter 5.2. However, the trend during the whole period is different compared to S&P 500 index. It would be interesting to see the results of testing the weak form of efficiency in Shanghai stock market.

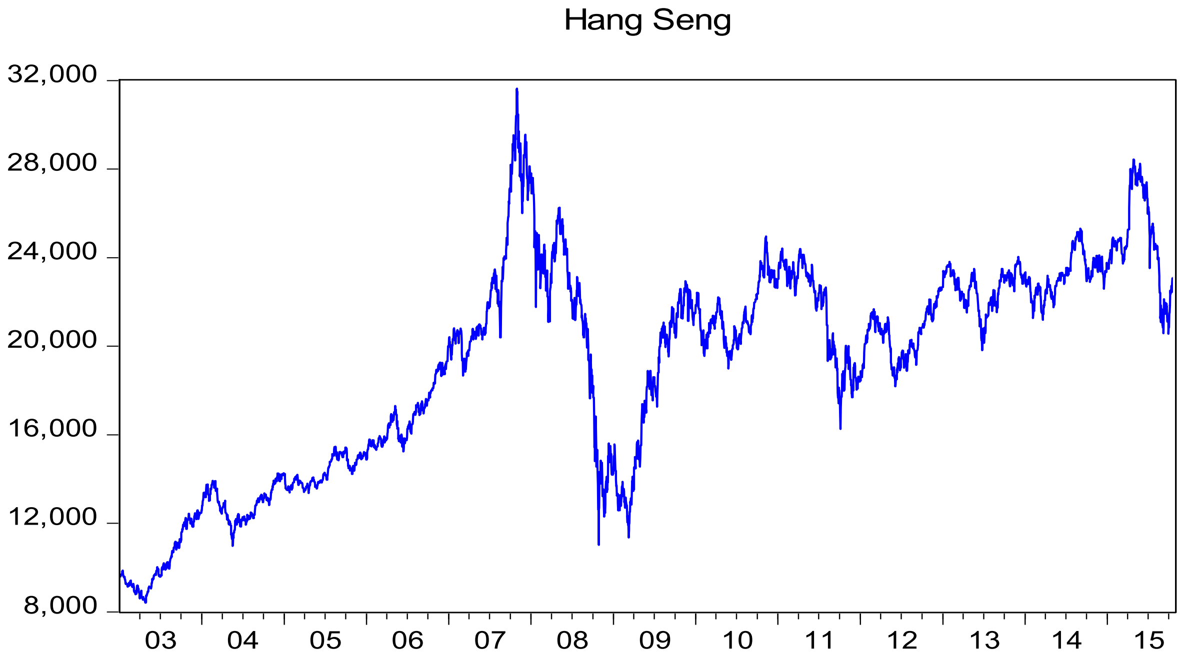
Figure 5.2: Daily closing prices for Shanghai composite stock index.

Source: own calculation in Eviews

The Figure 5.3 presents closing prices of Hang Seng index during the given time. We can see that there are more fluctuation in the volume comparing with the Shanghai composite stock index. Moreover, it has similar trends like S&P 500 index.

In addition to this, it has similar trends during 2014 to 2015 like Shanghai composite stock index. Since the Hang Seng index is more tightly related to the global economy, the results of testing the efficient market hypothesis maybe different compared to Shanghai stock market.

Figure 5.3: Daily closing prices for Hang Seng index.



Source: own calculation in Eviews

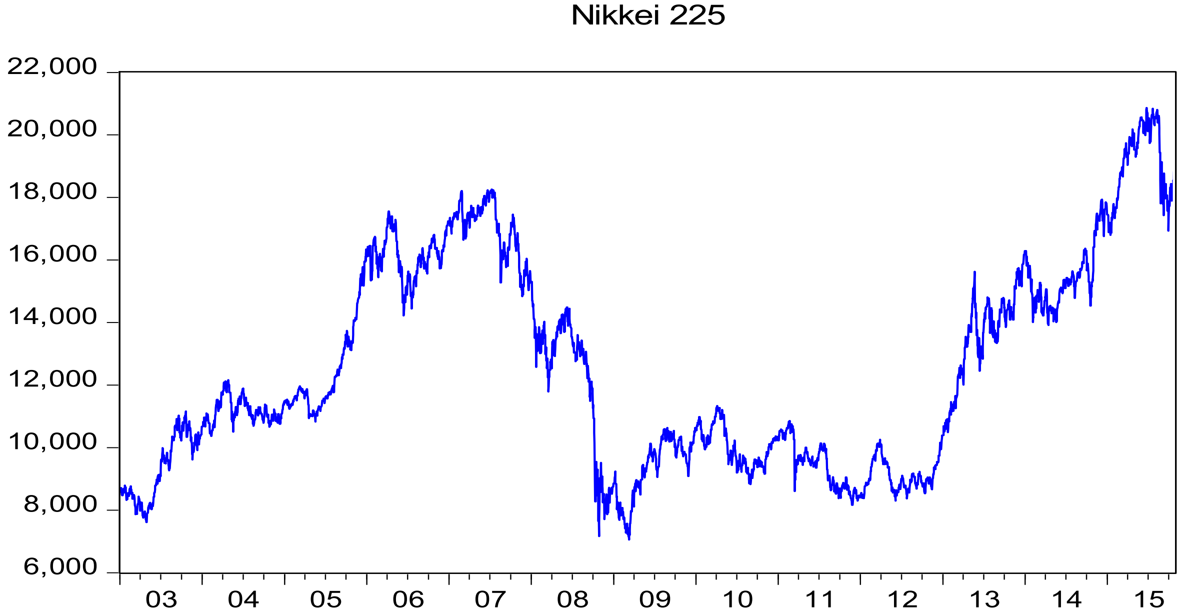
5.2.2 Data Sample from Tokyo

In this subchapter, we will describe the data sample from Tokyo stock market. The tradition of Japan is very similar to China, because they are both from Asia. However it is a developed country. So that Japanese stock market is more perfect than China.

The components of the Nikkei 225 stock index are reviewed once a year. It is a very important indicator for Japan, and also play a very significant role in the global financial market.

In Figure 5.4, we can see closing price for Nikkei 225 stock index in Tokyo Exchange during the given testing period. The development of Nikkei 225 index is similar to S&P. The reason is that both stock markets belong to developed countries. However in the development of Nikkei 225 stock index, there is an interesting phenomenon. We can see a rapid recovery after 2012.

Figure 5.4: Daily data of closing prices for Nikkei 225 stock index.



Source: own calculation in Eviews

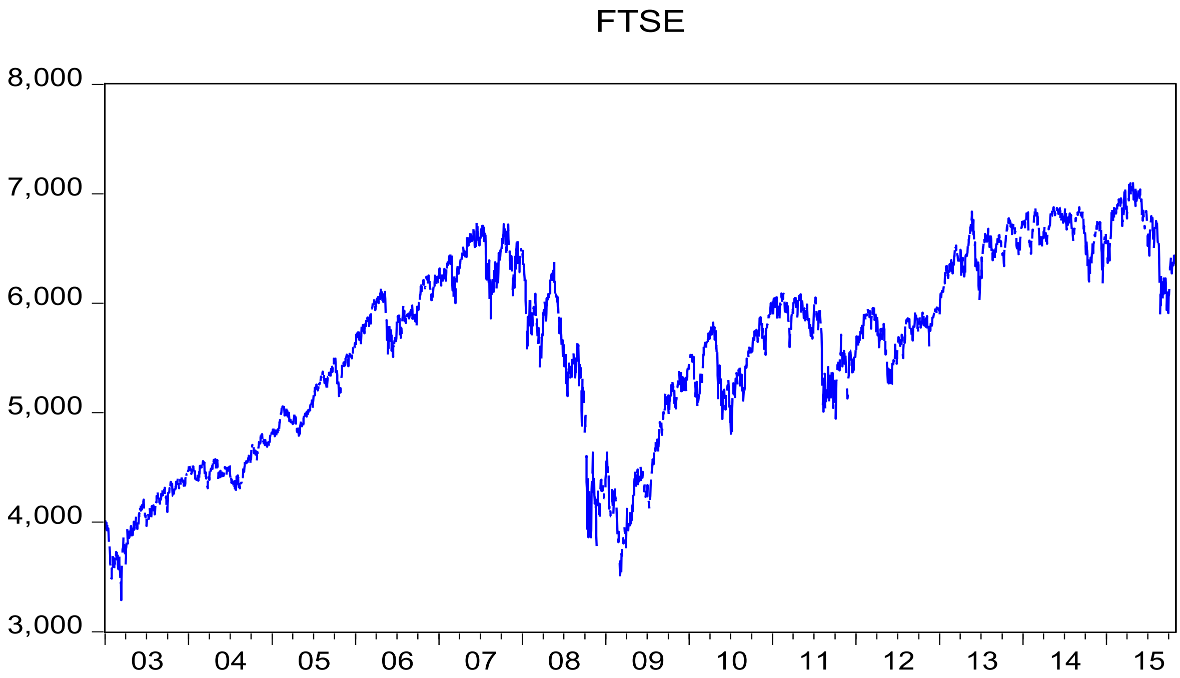
5.2.3 Data Sample from London

Our aim is to compare efficiency of the Asian stock markets and European stock market. Since London exchange market belongs to developed stock market, maybe we can expect similar results like in the case of Tokyo exchange market. Moreover, we can guess that UK is more mature financial market than China.

In this subchapter, we will describe the data sample from London stock market. FTSE 100 stock index can more fully reflect the situation of the London stock market. It is a comprehensive actuarial stock index and it covers about 80% market value on the London stock exchange. In addition, it also is one of the most popular investment instruments all over the world.

Figure 5.5 shows closing prices of FTSE stock index during the given testing period. The total period will be divided into pre-crisis, crisis and post-crisis periods. On the other hands, the shape of trending of this index is similar to S&P 500 index.

Figure 5.5: Daily closing prices for FTSE stock index.



Source: own calculation in Eviews

5.3 Logarithmic Returns

Figure 5.2, 5.3, 5.4 and 5.5 showed the trends of the observed indexes. If we want to develop a good regression model or apply some statistical tests, we need to use stationary data. Therefore, we will apply the logarithmic returns in this thesis.

We call P_t as the closing price of indexes at the time *t*. The formula of net return is defined as:

$$R_t = \frac{P_t}{P_{t-1}} - 1 = \frac{P_t - P_{t-1}}{P_{t-1}}. \tag{5.1}$$

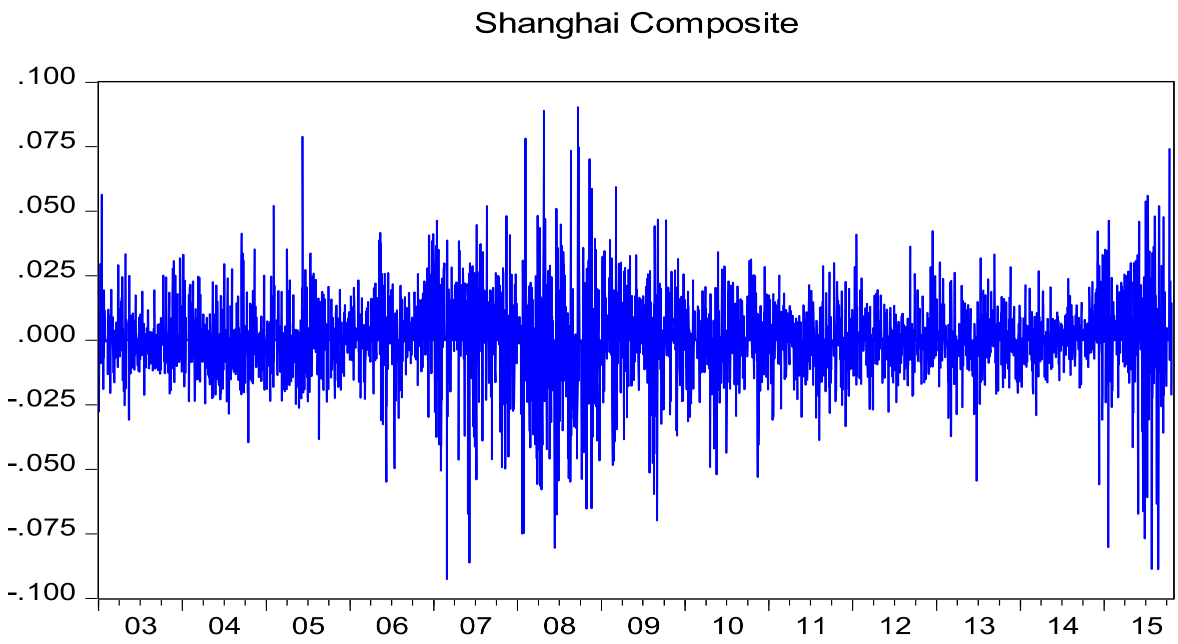
Time series of daily returns do not confirm assumptions of normal distribution, which we described in subchapter 4.2.1. As a result, we can change equation (5.1) to logarithmic returns to satisfy normal distribution and stationary of daily returns. The new formula will be calculated as:

$$r_t = \ln(1 + R_t) = ln\frac{P_t}{P_{t-1}} = lnP_t - lnP_{t-1}. \tag{5.2}$$

The equation (5.2) shows the difference of the logarithmic closing prices between time *t* and *t*-1. We apply this equation on the daily closing prices of Shanghai composite index, Hang Seng index, Nikkei 225 stock index and FTSE 100 index.

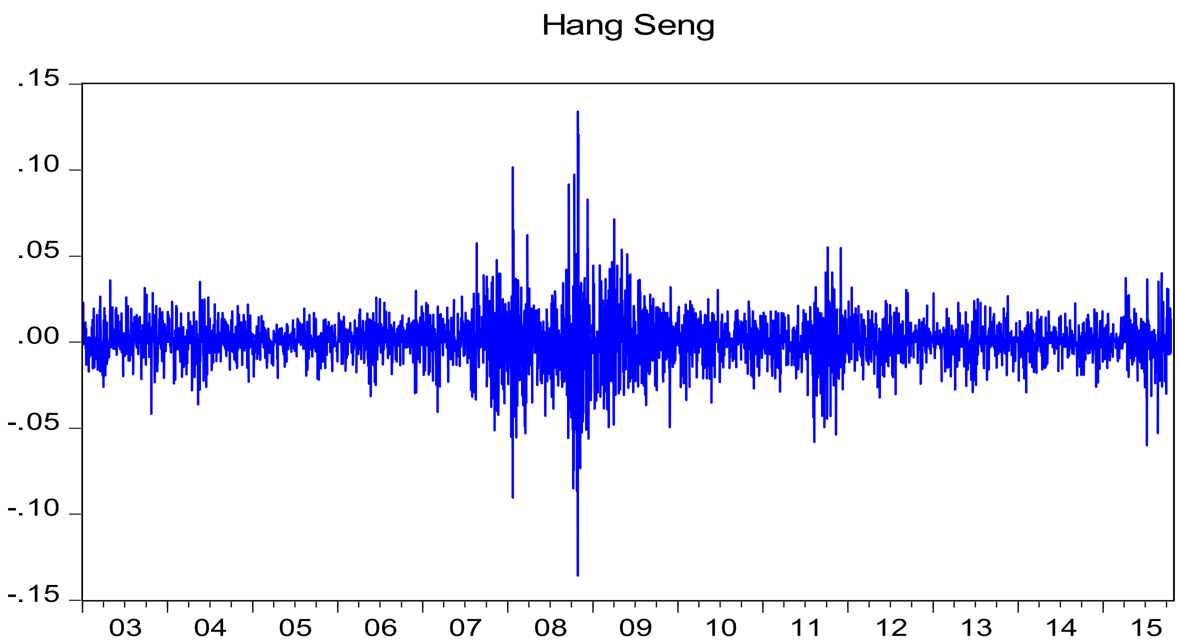
Therefore, Figure 5.6, Figure 5.7, Figure 5.8 and Figure 5.9 show the logarithmic returns that were computed on the basis closing price.

Figure 5.6: Daily logarithmic returns of Shanghai composite stock index



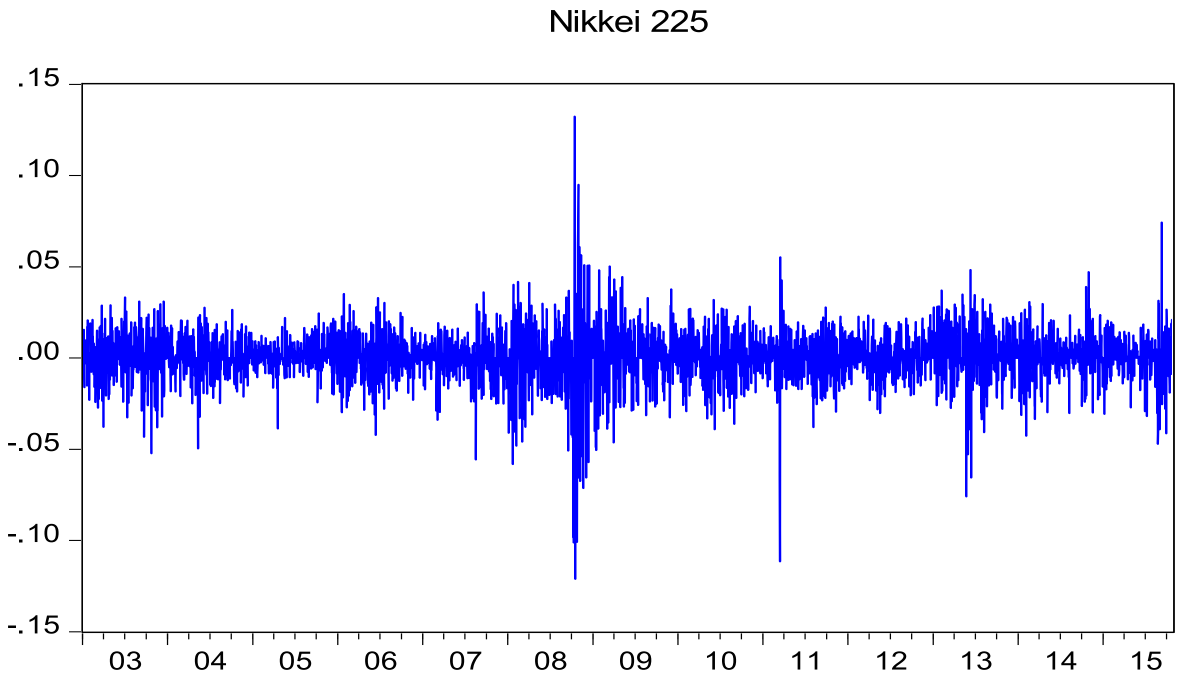
Source: Own calculation in Eviews

Figure 5.7: Daily logarithmic returns of Hang Seng stock index



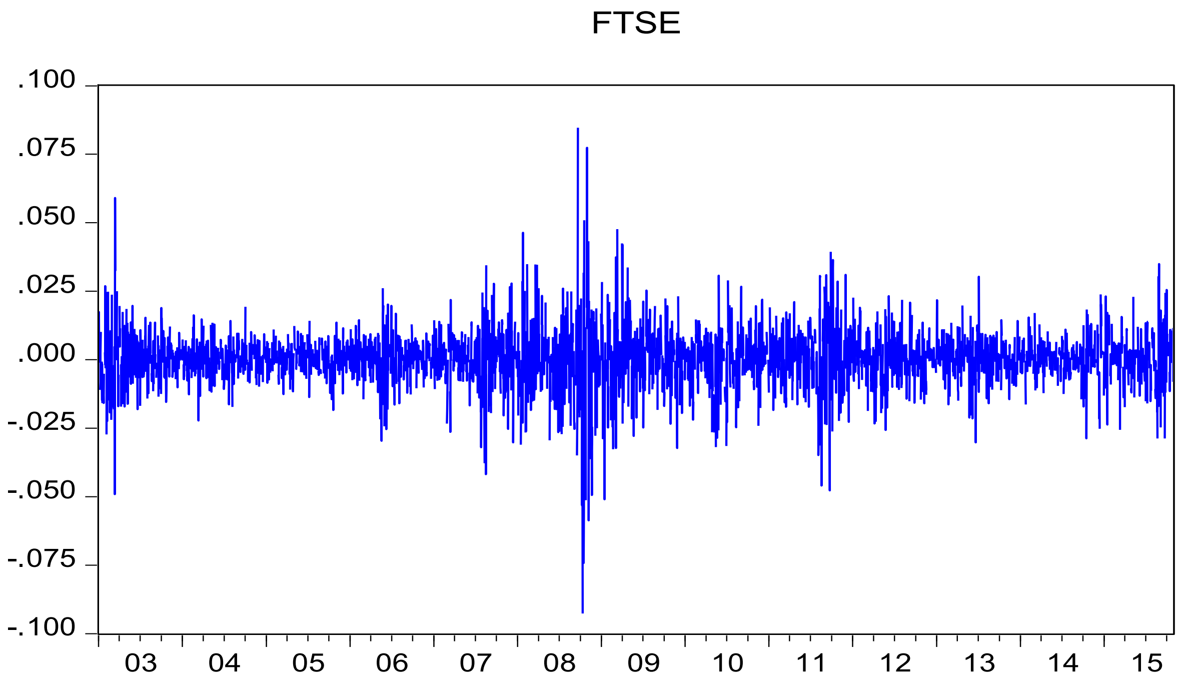
Source: Own calculation in Eviews

Figure 5.8: Daily logarithmic returns of Nikkei 225 stock index



Source: Own calculation in Eviews

Figure 5.9: Daily logarithmic returns of FTSE 100 stock index



Source: Own calculation in Eviews

These figures show that volatility is highest in time period of global financial crisis compare to other periods. Furthermore, it is easy to see that volatility of Shanghai composite stock index is different compared with other indexes. We can expect some differences between Chinese market (especially Shanghai stock market) and other markets when testing to the EMH in its weak form.

5.4 Descriptive Statistic for Return Series

In this subchapter, we will describe basic descriptive statistic for daily returns of Shanghai composite index, Hang Seng index, Nikkei 225 stock index and FTSE 100 index. We have already divided basic testing period into three sub-periods (pre-crisis period, crisis period and post-crisis period). Therefore, we have collected 12 groups of sample data descriptive statistics.

Table 5.1: Descriptive statistics of daily returns

	pre-crisis period	crisis period	post-crisis period	pre-crisis period	crisis period	post-crisis period
	Shanghai composite index			**Hang Seng index**		
Observations	1739	522	2427	1739	522	2427
Mean	0.0008	-0.0019	0.0002	0.0006	-0.0017	0.0003
Standard deviation	0.0122	0.0220	0.0125	0.0086	0.0246	0.0108
Skewness	-0.2842	0.0633	-0.8800	0.0927	0.2060	0.0230
Kurtosis	10.1873	5.6930	11.4440	7.3192	9.2361	8.1361
Jarque-Bera	3766.370	158.0787	7523.523	1354.217	849.5238	2667.853
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Nikkei 225 stock index			**FTSE 100 index**		
Observations	1739	522	2427	1739	522	2427
Mean	0.0004	-0.0017	0.0004	0.0004	-0.0017	0.0004
Standard deviation	0.0097	0.0215	0.0116	0.0086	0.0197	0.0103
Skewness	-0.4727	-0.3933	-0.5245	-0.1192	-0.1971	-0.0275
Kurtosis	6.4674	11.1442	10.5898	7.7932	6.5927	5.0680
Jarque-Bera	935.8941	1456.109	5936.535	954.8453	161.6500	245.0002
Probability	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Source: Own calculation in Eviews

Table 5.1 shows the basic descriptive statistic of all investigated indexes. It is obvious to see that the mean return are always negative during crisis period for all four indexes. It happened since all markets declined during crisis period. The global financial crisis had negative impact on global stock markets. Furthermore, on the basis of JB test which is described in subchapter 4.2.1, we can reject hypothesis of normal of distribution of returns at the 5% significance level in all cases.

Moreover, we can see the standard deviation during crisis period is larger than in other periods. This fact means that volatility of all markets was higher during crisis period, see Figure 5.6, 5.7, 5.8 and 5.9. Different values of descriptive statistics in different sub periods suggest also potentially different results when testing EMH.

5.5 Results of Testing the Weak Form of Efficiency

This chapter is aimed at testing the weak form of efficiency by linear methods and non-linear methods for the three different sub periods and four different stock markets. There will be presented results achieved using the variance ratio test, Ljung-Box test, runs test, White test, Engle's test and BDS test. In other words, we will compare these results achieved by application of different tests in different stock markets.

In order to capture the main aim of this thesis we will test the following hypothesis:

H_0: Stock market is efficient in its weak form.

H_1: Stock market is not efficient in its weak form.

If the stock market follow a martingale or random walk, we cannot reject H_0, so the stock market is efficient in its weak form.

5.5.1 Results of Testing the Efficiency by Linear Methods

Firstly, the results of linear tests that were defined in subchapter 4.1.1 will be presented in this subchapter.

If the probability of testing statistic is greater than 0.05, we cannot reject the null hypothesis. It means that this market efficient in its weak form. Inversely, if the probability of testing statistic is less than 0.05, we can the reject null hypothesis. Therefore, the market is not efficient.

a) Variance Ratio Test

This test evaluates the weak form of efficiency in the form of martingale as described in subchapter 3.6.1. The null hypothesis in this test is that stock market is a martingale. Table 5.2 shows that the result of variance ratio test during pre-crisis period for four given indexes.

Table 5.2: Results of variance ratio test during the pre-crisis period

	Shanghai Composite			**Hang Seng**		
Lags	Var. Ratio	*z*-Statistic	Prob.	Var. Ratio	*z*-Statistic	Prob.
2	0.9171	-1.5983	0.1100	0.9827	-0.4196	0.6748
4	0.8864	-1.2009	0.2298	0.9484	-0.6613	0.5084
6	0.9653	-0.2313	0.8171	0.9811	-0.1524	0.8789
8	1.0320	0.1454	0.8844	0.9810	-0.1036	0.9175
	Nikkei 225			**FTSE 100**		
2	0.9692	-1.0601	0.2891	1.0294	1.0690	0.2851
4	0.9556	-0.8259	0.4089	0.9983	-0.0387	0.9692
6	0.9324	-0.8038	0.4215	0.9056	-1.3069	0.1912
8	0.8692	-1.0216	0.3070	1.0420	0.3851	0.7002

Source: Own calculation in Eviews

In Table 5.2, we cannot reject the null hypothesis of a martingale since all probabilities are greater than 0.05. Therefore, these four stock markets are considered efficient in its weak form during pre-crisis period.

Table 5.3 shows that the results of variance ratio test during crisis period for four investigated indexes.

As shown in Table 5.3, achieved results are same with Table 5.2. We cannot reject the null hypothesis of a martingale since all probabilities are greater than 0.05. In other words, all four stock markets are efficient in its weak form even during crisis period.

Table 5.3: Results of variance ratio test during the crisis period

	Shanghai Composite			**Hang Seng**		
Lags	Var. Ratio	*z*-Statistic	Prob.	Var. Ratio	*z*-Statistic	Prob.
2	0.9694	-0.5524	0.5807	0.9022	-1.5385	0.1239
4	0.9221	-0.8303	0.4064	0.8315	-1.4160	0.1568
6	1.0001	0.0009	0.9993	0.7471	-1.4124	0.1578
8	0.9659	-0.1543	0.8774	0.6941	-1.2100	0.2263
	Nikkei 225			**FTSE 100**		
2	0.9709	-0.5918	0.5540	1.0155	0.3845	0.7006
4	0.9040	-0.8952	0.3707	0.8984	-1.3689	0.1710
6	0.8218	-1.0293	0.3033	0.8083	-1.6181	0.1056
8	0.7700	-0.8665	0.3862	0.9348	-0.3485	0.7275

Source: Own calculation in Eviews

Table 5.4 shows that the result of variance ratio test during post-crisis period for all four analysed indexes.

Table 5.4: Results of variance ratio test during the post-crisis period

	Shanghai Composite			**Hang Seng**		
Lags	Var. Ratio	*z*-Statistic	Prob.	Var. Ratio	*z*-Statistic	Prob.
2	1.0266	0.5874	0.5570	0.9917	-0.3258	0.7446
4	1.0266	0.3264	0.7441	1.0096	0.2113	0.8327
6	1.1104	0.8702	0.3842	1.0046	0.0660	0.9474
8	1.2111	1.1277	0.2595	1.0189	0.1817	0.8558
	Nikkei 225			**FTSE 100**		
2	0.9463	-1.4909	0.1360	1.0311	1.0565	0.2907
4	0.9195	-1.3196	0.1870	0.8761	-1.4628	0.1435
6	0.9035	-1.0793	0.2804	0.7766	-1.6046	0.1086
8	0.9136	-0.6645	0.5064	0.8313	-0.7732	0.4394

Source: Own calculation in Eviews

In Table 5.4, the result also is the same like in previous sub periods. To sum up, we have not detected any significant linear dependency using variance ratio test. That is why, the null hypothesis that all markets follow martingale in all sub-periods cannot be rejected.

b) Ljung-Box Test

This test evaluates the weak form of efficiency in the form of Random Walk 3 as defined in subchapter 3.6.2. The Ljung-Box test explores autocorrelation structure of logarthmic returns. In other words, this test evaluates just linear dependency in data samples.

Table 5.5: Results of Ljung-Box Test during the pre-crisis period

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
lag	Q-Stat.	Prob.	Q-Stat.	Prob.	Q-Stat.	Prob.	Q-Stat.	Prob.
1	4.2496^{*}	0.039	0.0016	0.968	1.9846	0.159	5.4998	0.053
2	4.4072	0.110	2.9038	0.234	2.3520	0.309	5.9564	0.061
3	8.3594^{*}	0.039	10.513	0.055	3.3584	0.340	6.1946	0.103
4	11.340^{*}	0.023	11.933	0.058	5.0313	0.284	7.5589	0.109
5	16.234^{*}	0.006	12.585	0.068	5.7531	0.331	8.1013	0.151
6	20.858^{*}	0.002	12.585	0.052	6.0832	0.414	8.1114	0.230
7	21.275^{*}	0.003	13.350	0.064	6.1193	0.526	9.8170	0.199
8	24.077^{*}	0.002	14.639	0.067	6.1975	0.625	10.052	0.261
9	25.016^{*}	0.003	14.820	0.096	6.9252	0.645	11.308	0.255
10	25.037^{*}	0.005	15.085	0.129	14.155	0.166	11.308	0.334

Source: Own calculation in Eviews

If p-value is greater than 0.05, we cannot reject H_0. On the contrary, if p-value is less than 0.05, we can reject H_0. Table 5.5 shows the results of Ljung-Box test up tp 10 lags for all four given indexes during the pre-crisis period.

In Table 5.5, we can observe nearly all probabilities for Shanghai composite index are less than 0.05. Therefore, we can reject the null hypothesis of efficiency in the form of RW3. It means there is very strong autocorrelation. Contrary to Shanghai composite index, all probabilities of other three indexes are greater than 0.05. It means that there are no autocorrelations in Hang Seng index, Nikkei 225 index and FTSE 100 index during pre-crisis period.

Therefore, in the pre-crisis period, only Shanghai stock market is not efficient. The stock markets of Hong Kong, Tokyo and London exhibit weak form of efficiency. in the form of RW 3.

Table 5.6 shows the results of Ljung-Box test for all four given indexes during the crisis period.

Table 5.6: Results of Ljung-Box Test during the crisis period

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
lag	Q-Stat.	Prob.	Q-Stat.	Prob.	Q-Stat.	Prob.	Q-Stat.	Prob.
1	2.7263	0.099	6.2104*	0.013	0.2796	0.597	0.1161	0.733
2	2.9213	0.232	8.6682*	0.013	0.3796	0.827	0.2735	0.872
3	6.0757	0.108	14.038*	0.003	3.7732	0.287	0.2789	0.964
4	6.5038	0.165	16.254*	0.003	8.7197	0.068	1.5712	0.814
5	6.5271	0.258	16.269*	0.006	8.7865	0.118	1.5739	0.904
6	7.2999	0.294	16.802*	0.010	10.796	0.095	6.7679	0.343
7	8.1102	0.323	16.808*	0.019	10.859	0.145	8.2760	0.309
8	8.4910	0.387	17.833*	0.023	12.655	0.124	9.3523	0.313
9	8.5581	0.479	17.845*	0.037	13.532	0.140	9.5692	0.386
10	8.5677	0.574	18.959*	0.041	13.538	0.195	9.5907	0.477

Source: Own calculation in Eviews

From Table 5.6, we can see that the all probabilities for Shanghai composite index are greater than 0.05. It means that we cannot reject H_0 and there is no statistically significant autocorrelation during crisis period. However, all probabilities are less than 0.05 in Hang Seng index, so that there is a very strong autocorrelation. In addition, all probabilities of Nikkei 225 and FTSE 100 indexes are also greater than 0.05, so that there are no significant autocorrelations.

During the crisis period, only Hong Kong stock market is not efficient market. The stock markets of Shanghai, Tokyo and London satisfy the weak form of efficiency. In addition, we found that the occurrence of global crisis didn't influence the weak form of efficiency for Tokyo and London stock markets. Results of Ljung-Box test for Chinese markets are suprising.

Table 5.7 shows that the result of Ljung-Box test for these four given indexes during the post-crisis period.

Table 5.7: Results of Ljung-Box Test during the post-crisis period

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
lag	Q-Stat.	Prob.	Q-Stat.	Prob.	Q-Stat.	Prob.	Q-Stat.	Prob.
1	0.0109	0.917	0.4390	0.508	5.7072	0.057	0.0089	0.925
2	2.5437	0.280	1.0922	0.579	5.9003	0.062	0.0104	0.995
3	10.402*	0.015	1.0937	0.779	7.5041	0.057	0.2080	0.976
4	10.402*	0.034	1.7403	0.783	8.6400	0.071	0.4189	0.981
5	10.802*	0.055	4.5460	0.474	8.7920	0.118	0.4365	0.994
6	16.765*	0.010	8.9766	0.175	9.9667	0.126	1.4363	0.964
7	17.604*	0.014	9.5147	0.218	10.100	0.183	1.4683	0.983
8	27.456*	0.001	11.385	0.181	10.105	0.258	1.5537	0.992
9	27.892*	0.001	15.735	0.073	10.141	0.339	1.7200	0.995
10	28.229*	0.002	16.689	0.082	10.581	0.391	2.9349	0.983

Source: Own calculation in Eviews

In Table 5.7, we can observe the most of probabilities for Shanghai composite index is less than 0.05. We can reject H_0 so that there is very strong autocorrelation during post-crisis period. The results of Shanghai composite index are very different when comparing to other stock indexes.

Moreover, all probabilities of Hang Seng index, Nikkei 225 index and FTSE 100 index are greater than 0.05. It means that there are no autocorrelation during post-crisis period in these markets. The result are same like in the pre-crisis period, the stock markets of Hong Kong, Tokyo and London follow the weak form of efficiency. However, Shanghai stock market is not efficient since returns don't follow RW3 model. Achieved results are logical and expectable with exception of Shanghai market. It seems that global financial crisis affected efficiency of Chinese markets.

c) Runs Test

This test evaluates the weak form of efficiency in the form of Random Walk 1. Table 5.8 shows the results of runs tests during three sub-periods for all four given indexes. CJ ratio is defined as a share of runs and breaks.

Table 5.8: Results of runs Test during three sub-periods

		Runs	Breaks	CJ ratio	*z*-statistic
pre-crisis period	**Hang Seng**	614	661	0,9289	-1,2695
	Shanghai Composite	594	683	0,8697	$-2{,}3283^{*}$
	Nikkei 225	634	648	0,9784	-0,3868
	FTSE 100	644	638	1,0094	0,1684
crisis period	**Hang Seng**	167	211	0,7915	$-2{,}0272^{*}$
	Shanghai Composite	176	198	0,8889	-1,0744
	Nikkei 225	187	182	1,0275	0,2639
	FTSE 100	198	175	1,1314	1,2692
post-crisis period	**Hang Seng**	846	881	0,9603	-0,8255
	Shanghai Composite	916	816	1,1225	$2{,}5501^{*}$
	Nikkei 225	894	839	1,0656	1,3645
	FTSE 100	901	832	1,0829	1,7262

Source: Own calculation in Excel

If the absolute value of z-statistic is greater than ± 1.96, we reject the null hypothesis of RW1. The absolute values of 1.96 are critical values of normalized normal distribution N (0, 1) at 5% significance level.

As shown in Table 5.8, during the pre-crisis period and post crisis period, we can see that the absolute value of z-statistic is greater than 1.96 in the case of Shanghai composite index. It means that we reject the null hypothesis of RW1. However, so we cannot reject the null hypothesis of random walk for other indexes

Nevertheless, during crisis period, there are different results. We can see that the absolute value of z-statistic is greater than 1.96 in the case of Hang Seng index. At the same time, Shanghai composite index, Nikkei 225 index and FTSE 100 index have value of z-statistic less than 1.96, so we cannot reject the null hypothesis of RW1.

Consequently, when completing the runs test achieved results are same like in the case of Ljung-Box test. The stock markets of Hong Kong, Tokyo and London follow weak form of efficiency during pre-crisis period and post-crisis period. However Shanghai stock market is not efficient during the pre-crisis period and post-crisis periods.

Contrary to that, the stock markets of Shanghai, Tokyo and London follow weak form of efficiency during crisis period. However, Hong Kong stock market is not efficient during crisis period according runs test.

5.5.2 Results of Testing the Efficiency by Nonlinear Methods

Next, we will show the results of nonlinear methods applied in this subchapter. Later we will compare the results of linear and non-linear methods. In previous subchapter 5.5.1, we utilised linear statistical methods to verify linear dependencies in data sample.

If we don't reject the null hypothesis when applying linear methods, it doesn't mean that there cannot exist nonlinear dependency. That is why our next step is to utilise also nonlinear tests that are capable to investigate also nonlinear dependencies in daily returns. For the purpose of this subchapter, there will be applied nonlinear tests that were defined in subchapter 4.1.2.

If the probability of testing statistic is greater than 0.05, it means that we cannot reject H_0. Meanwhile, if probability is less than 0.05, it means that we can reject H_0.

a) White Test

This test evaluates the weak form of efficiency in the form of Random Walk 2.

Table 5.9 shows that the result of White test during all three sub-periods for all four analysed indexes.

Table 5.9: Results of White Test during three sub-periods

		Shanghai Composite	Hang Seng	Nikkei 225	FTSE 100
pre-crisis period	F-statistic	3.0232^{*}	3.3370^{*}	4.4960^{*}	2.7568
	Probability	0.0489	0.0358	0.0113	0.0638
crisis period	F-statistic	0.1053	19.5230^{*}	3.5750^{*}	0.1360
	Probability	0.9001	0.0000	0.0287	0.8729
post-crisis period	F-statistic	40.9570^{*}	13.5416^{*}	75.9874^{*}	0.1075
	Probability	0.0000	0.0000	0.0000	0.8981

Source: Own calculation in Eviews

As shown in Table 5.9, we can see that the probability of F-statistic of Shanghai composite index is greater than 0.05 during crisis period. Moreover, the probability of F-statistic in the case of FTSE 100 index is greater than 0.05 during all periods. Therefore, we cannot reject H_0, it means there are not detected nonlinear dependencies in these time series.

However, White test detected statistically significant nonlinear dependences for Hang Seng index and Nikkei 225 index during all periods. For Shanghai composite index, nonlinear dependency was found out during per-crisis and post-crisis period.

Results of White test are different from those achieved by linear methods. The stock markets of Hong Kong and Tokyo don't follow weak form of efficiency during all periods. Even though we applied the non-linear method of testing, London stock market is still efficient. However, the result of White test confirmed results achieved by Ljung-Box Test for Shanghai stock market. Shanghai stock market satisfy the weak form of efficiency surprisingly only during crisis period.

b) Engle´s Test

This test evaluates the weak form of efficiency in the form of Random Walk 2. If at least one p-value is less than 0.05, we can reject the null hypothesis. If more than one probability is less than 0.05 we can also reject the null hypothesis. In addition to this, we can say that dependency is stronger than in the case when only one p-value is less than 0.05.

Table 5.10 presents the results of Engle's test for four given investigated indexes during the pre- crisis period.

Table 5.10: Results of Engle's Test during pre-crisis period.

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
Variable	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.
RESID^2(-1)	2.0930*	0.0365	0.7601	0.4473	0.9747	0.3298	0.5311	0.5954
RESID^2(-2)	1.7846	0.0745	1.7516	0.0800	1.0363	0.3002	-0.2819	0.7781
RESID^2(-3)	1.9392	0.0526	1.8135	0.0699	2.3680*	0.0180	-0.5401	0.5892
RESID^2(-4)	0.4267	0.6697	2.8923*	0.0039	-0.4981	0.6185	-0.5121	0.6215
RESID^2(-5)	2.3277*	0.0200	5.6159*	0.0000	1.0511	0.2933	-0.7199	0.4717

Source: Own calculation in Eviews

As shown in Table 5.10, the H_0 can be rejected for Shanghai composite index, Hang Seng index and Nikkei 225 index since probabilities are less than 0.05. We found out that, there is statistically significant nonlinear dependency in time series. Shanghai, Hong Kong and Tokyo are not efficient during pre-crisis period. However, all probabilities are greater than 0.05 in the case of FTSE. Consequently, London market exhibits weak-form of efficient market during the pre-crisis period.

Table 5.11 shows the results of Engle's test during crisis period for all four analysed indexes.

Table 5.11: Results of Engle's Test during crisis period.

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
Variable	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.
RESID^2(-1)	0.4159	0.6777	3.2553*	0.0012	1.2343	0.2176	0.9851	0.3247
RESID^2(-2)	-1.1452	0.2527	3.3850*	0.0008	8.0364*	0.0000	12.3341*	0.0000
RESID^2(-3)	1.1300	0.2590	6.3895*	0.0000	-0.2934	0.7693	−4.0865*	0.0000
RESID^2(-4)	-1.7038	0.0890	-0.5426	0.5877	1.3639	0.1732	−2.9249*	0.0035
RESID^2(-5)	-0.5919	0.5542	-1.2273	0.2203	1.0650	0.2874	10.5550*	0.0000

Source: Own calculation in Eviews

In Table 5.11, the H_0 cannot be rejected surprisingly only for Shanghai composite index. Therefore, there is not significant nonlinear dependency during crisis period in data sample. Shanghai stock market follows weak-form of efficiency during the crisis period. On the other hand, the probabilities of some t-statistics of other indexes are less than 0.05, so they cannot be considered efficient market during the crisis period. Achieved results are different from those got by White test for London stock exchange.

Table 5.12 presents the results of Engle's test during post-crisis period for all four given indexes.

Table 5.12: Results of Engle's Test during post-crisis period.

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
Variable	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.	t-Statistic	Prob.
RESID^2(-1)	7.0339*	0.0000	3.6829*	0.0002	12.5555*	0.0000	-0.3870	0.6989
RESID^2(-2)	2.5661*	0.0103	0.2479	0.8042	−2.0409*	0.0414	-0.5976	0.5504
RESID^2(-3)	6.0443*	0.0000	6.3134*	0.0000	2.0964*	0.0362	-0.5675	0.5706
RESID^2(-4)	3.0929*	0.0020	1.8341	0.0668	1.1492	0.2506	-0.5310	0.5956
RESID^2(-5)	0.9958	0.3195	2.0261*	0.0429	-0.6092	0.5424	0.0647	0.9485

Source: Own calculation in Eviews

Table 5.12 shows that there can be observed nonlinear dependency for all markets except FTSE 100. We can reject null hypothesis, there is nonlinear dependency during the post-crisis period. Therefore, Shanghai, Hong Kong and Tokyo are not efficient during the post-crisis period. However, London stock market exhibits weak-form of efficient market during the post-crisis period.

c) BDS Test

This test evaluates the weak form of efficiency in the form of Random Walk 2.This test is a portmanteau test for time based dependence in a series. It can be used for testing against a variety of deviations from independence including linear dependence and nonlinear dependence of chaos.

Table 5.13 shows that the result of BDS test during pre-crisis period for these four given indexes.

Table 5.13: Results of BDS Test during the pre-crisis period.

	Shanghai Composite		Hang Seng		Nikkei 225		FTSE 100	
Dimension	z-Stat.	Prob.	z-Stat.	Prob.	z-Stat.	Prob.	z-Stat.	Prob.
2	3.6270*	0.0003	2.8154*	0.0049	3.5031*	0.0005	4.3413*	0.0000
3	2.2453*	0.0247	-0.0449	0.9642	1.4308	0.1525	3.5476*	0.0004
4	1.8684	0.0617	-1.4781	0.1394	0.4377	0.6616	2.6151*	0.0089
5	1.8347	0.0666	−2.5151*	0.0119	-0.1547	0.8771	2.4922*	0.0127
6	1.9151	0.0555	−2.5871*	0.0097	-0.1976	0.8434	2.1575*	0.0310

Source: Own calculation in Eviews

As shown in Table 5.13, the probability of z-statistics of these four indexes are usually less than 0.05. It means that we can reject null hypothesis, which means that there is nonlinear dependency for all indexes during the pre-crisis period. Therefore, all markets are not efficient during the pre-crisis period. Table 5.14 presents the results of BDS test during the crisis period for all four given indexes.

Table 5.14: Results of BDS Test during crisis period.

	Shanghai Composite		Hang Seng		Nikkei 225		FTSE 100	
Dimension	z-Stat.	Prob.	z-Stat.	Prob.	z-Stat.	Prob.	z-Stat.	Prob.
2	−3.4427*	0.0006	1.2313	0.2182	3.3435*	0.0008	2.6424*	0.0082
3	−1.9960*	0.0459	1.9843*	0.0472	3.2771*	0.0010	1.5386	0.1239
4	-0.8108	0.4175	2.7006*	0.0069	3.4582*	0.0005	1.2846	0.1989
5	-0.3854	0.6999	3.0269*	0.0025	3.6440*	0.0003	1.5453	0.1223
6	-0.2302	0.8179	3.5302*	0.0004	3.9271*	0.0001	1.4434	0.1489

Source: Own calculation in Eviews

Table 5.14 shows results of BDS test for the crisis period. Markets are not again efficient during crisis period. It is interesting to see that there is only one probability is less than 0.05 in the case of FTSE 100 index. Therefore, the dependency observed in FTSE 100 index is weaker than others. Table 5.15 shows the results of BDS test during the post-crisis period for all four given indexes.

Table 5.15: Results of BDS Test during post-crisis period.

	Shanghai Composite		**Hang Seng**		**Nikkei 225**		**FTSE 100**	
Dimension	z-Stat.	Prob.	z-Stat.	Prob.	z-Stat.	Prob.	z-Stat.	Prob.
2	4.4217*	0.0000	5.5872*	0.0000	2.9113*	0.0036	2.8801*	0.0040
3	2.3474*	0.0189	3.5412*	0.0004	1.1252	0.2605	3.2000*	0.0014
4	1.4843	0.1377	2.0834*	0.0372	0.2226	0.8238	2.5137*	0.0119
5	1.1156	0.2646	1.3995	0.1617	-0.0920	0.9267	1.9093	0.0562
6	1.0694	0.2849	1.3384	0.1808	-0.3407	0.7333	1.4655	0.1428

Source: Own calculation in Eviews

In Table 5.15, the results are same like in Table 5.13 and Table 5.14. All four markets are not efficient during the post-crisis period. Results of BDS test significantly differ from those achieved by other nonlinear tests.

5.6 Summary of Results

Subchapter 5.6 is mainly aimed to make a summary of the results achieved in Chapter 5. We applied the theory which has been described in Chapter 4 into practice using real data from financial market. In the practical part, we got different results of statistical tests using data from four stock markets during three sub-periods (pre-crisis, crisis and post-crisis). We defined 3 sub periods to capture dynamics of development of efficiency.

Moreover, we can compare the differences of results achieved by linear methods and nonlinear methods. Results of all tests can be theoretically different since there are applied different trading rules in different stock markets (see subchapter 5.1). Those tests examined efficient market hypothesis in different forms (martingale, RW2, RW3).

Table 5.16 in this subchapter is derived from results of statistical test achieved by own calculation. In this table 5.16, letter *E* means this market is efficient in its weak form, and letter *N* means this market is not efficient.

The variance ratio test examines just linear dependencies in the data sample. According this test there are no statistically significant linear dependency so that these four markets are efficient during all periods.

Then the Ljung-Box test and runs test delivered same results. We found out that there are statistically significant linear dependencies in Shanghai composite index and Hang Seng index. Namely, during the pre-crisis and post-crisis periods, Shanghai stock market is not efficient market. On the other hand, we have not observed linear dependency in crisis period. Contrary to that, Hong Kong stock market is not efficient market during the crisis period.

Table 5.16: Comparison of results.

		Linear Methods			**Nonlinear Methods**		
		V-R	L-B	Runs	White	Engle's	BDS
Shanghai composite index	Pre-crisis	E	N	N	N	N	N
	Crisis	E	E	E	E	E	N
	Post-crisis	E	N	N	N	N	N
Hang Seng index	Pre-crisis	E	E	E	N	N	N
	Crisis	E	N	N	N	N	N
	Post-crisis	E	E	E	N	N	N
Nikkei 225 index	Pre-crisis	E	E	E	N	N	N
	Crisis	E	E	E	N	N	N
	Post-crisis	E	E	E	N	N	N
FTSE 100 index	Pre-crisis	E	E	E	E	E	N
	Crisis	E	E	E	E	N	N
	Post-crisis	E	E	E	E	E	N

Source: Own calculation

As shown in Table 5.16, by grey colour, we can consider the most of markets are efficient in its weak form when applying linear methods. However, if we don't identify any linear dependency in data sample, it doesn't mean that there is no dependency at all. Therefore, we applied also the nonlinear methods that are stronger than linear methods, since they are more efficient and powerful when detecting dependency in data samples.

In next step, we examined nonlinear dependency in data with a help of White test and Engle's test. There were observed statistically significant nonlinear dependencies in Hang Seng index and Nikkei 225 index. Therefore, Hong Kong and Tokyo are not efficient markets during all periods. Shanghai stock markets exhibits the weak-form efficiency surprisingly only during crisis period. London stock market is most efficient than others, it is not efficient only during crisis period according to Engle's test.

However, the BDS test, that is the strongest and very powerful one, can examine also nonlinear dependency in data. To sum up, when applying the BDS test we found out nonlinear dependency in the all data sample which means that all four markets are not efficient according the BDS test.

When making overall evaluation of all test, it can be said that London stock markets is the most efficient market followed by Tokyo, Hong Kong and Shanghai. However, during crisis period, Shanghai stock market surprisingly exhibits the weak-form of efficiency according to majority of tests.

When working with Chinese data (Shanghai), different and unexpected results of tests can be explained by some institutional rules applied in Chinese market that are different from those applied in UK or Japan, different trading rules, different market microstructure, composition and computation of Chinese index, and so on. Basic features of Shanghai market were described in Chapter 5.1.1. To sum up, Chinese market still belongs to emerging markets and has its own rules.

When assessing the overall efficiency of stock markets, it is necessary to bear in mind that the about conclusions are statistically significant. However, it is also necessary to examine its economic significance since provided tests didn't take into account information and transaction on costs. Moreover, we also abstracted from risk premium. However, achieved results imply that in the case of inefficiency it is possible to build a predictive model whose predictions are more accurate than random walk or martingale model.

6. Conclusion

In stock markets, many investors try to get profits through transactions in the stock exchange. For obtaining profits, they usually apply many methods when doing decision making and in order to find imperfections on markets. Therefore, it is interesting to investigate whether stock markets are efficient or not.

EMH is one of basic approaches to analysis stock markets. The main idea is no investor is able to attain greater profitability than another in efficient market, since the prices always fully reflect all available information.

There are three levels of efficient market: weak form, semi-strong form and strong form. In weak form, the price has already reflected the past stock's price information. If a market is weak form of efficiency, the stock price do not reflect present and future, but do reflect the past. Therefore, investors can use fundamental analysis to obtain excess returns.

This thesis was focused on testing the weak form of EMH using data from Asian and European stock markets. One of the most important reason for testing both emerging markets and developed markets was that to realize the differences between those markets.

The main goal of this diploma thesis was to test the weak form of efficiency in different stock markets using linear and nonlinear methods. For the purpose of this thesis, we used daily time series of Chinese, Japanese and British stock markets covering the period from 01/01/2003 to 10/30/2015. Moreover, there were set up two sub-goals. The first one was to compare the linear and nonlinear methods of testing the efficiency on stock index under three sub-period for Chinese, Japanese and British stock markets. The second sub-goal was to compare the difference of results in weak-form of efficiency between Shanghai stock market, and Hong Kong stock market. The third sub-goal was to evaluate impact of global financial crisis on efficiency of investigated stock markets.

The whole thesis was divided into 6 parts, including "Introduction" and "Conclusion". Methodological part of thesis's consisted of chapter 2, 3, 4, while chapter 5 was application part.

The introduction chapter clearly summarized main content of thesis and all chapter, then set up the goals of this thesis.

Chapter 2 introduced basic approaches to analyse stock market. The basic approaches contained fundamental analysis, technical analysis and psychological analysis.

Chapter 3 also belonged to methodological part of thesis. It emphasized efficient market hypothesis which would be verified in following chapter. The definition, forms, assumptions, characteristics and models of efficient market hypothesis were briefly described in this part. Meanwhile, the description of martingale, fair game and random walk models was also content of Chapter 3.

In Chapter 4, we described statistical tests applied when testing the information efficiency which contain linear and nonlinear methods. The linear tests includes variance ratio test, Ljung-Box test, runs test and the nonlinear methods like White test, Engle's test, BDS test. Finally, we described possible of testing efficiency and features of financial time series.

Chapter 5 was the most important part of the whole thesis. This part delivered results of empirical testing the weak form of efficiency. We used linear methods and nonlinear methods to calculate the results of test using data from three sub-periods, then obtained results were compared and summarised in this chapter.

As a whole, the main goal of this thesis was fulfilled. When using variance ratio test, all four markets follow weak form of efficiency during all periods. According to Ljung-Box test and runs test, only Shanghai stock market was not efficient market during pre-crisis and post-crisis period, while Hong Kong stock market was not efficient market during crisis period. When applying White and Engle's tests, Hong Kong and Tokyo were not efficient markets during all periods. Finally, BDS test shown that all four stock markets are not efficient at all.

When it comes to first sub-goal, the nonlinear methods were stronger than linear methods. According to nonlinear methods, the most of markets were not efficient. The reason for that is the fact that linear test are able to detect just linear dependencies while nonlinear methods are more powerful.

Regarding the second sub-goal, Shanghai stock market exhibits different results of testing when compared to Hong Kong stock market. Hong Kong market behave similarly to developed stock markets (Tokyo, London) and achieved results of thesis are logical and expectable. The null hypothesis of efficiency was rejected using all nonlinear methods and also in crisis period when using some linear methods. Results of provided test of efficiency using data from Shanghai stock market are just opposite. Shanghai stock market is efficient surprisingly during crisis period according all tests except the BDS test.

The reason for that is that Chinese market still belongs to emerging markets, and Shanghai stock market has many different institutional regulations compared with other stock markets.

For the third sub-goal, the impact of global financial crisis on efficiency is not great. For developed countries, there are nearly no difference between crisis period and other periods. However, Shanghai stock market is efficient only during crisis period. Moreover, Hong Kong stock market is not efficient only during crisis period.

To sum up, the main goal and all sub-goals of this thesis were fulfilled. However, some arguments still existed. For example, it would be useful to analyse why Shanghai stock market exhibits the weak-form of efficiency during crisis period.

Efficiency should not be understood in a static sense as an immediate adjustment of prices to new information. It should take into account market dynamics. From the practical point of view, this thesis can be a support for financial analysis. In contrast to other papers, this thesis captured the dynamics of development the weak form of efficiency over time.

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Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

List of Abbreviations

ARCH: Autoregressive Conditional Heteroscedasticity Model

COV: Covariance

EMH: Efficient Market Hypothesis

EMA: Exponential Moving Average

GARCH: Generalized Autoregressive Conditional Heteroscedasticity Model

HKEX: Hong Kong Exchange

IID: Independently and Identically Distributed

JB: Jarque-Bera Statistical Test

OLS: Ordinary Least Squares

RSI: Relative Strength Index

RWH: Random Walk Hypothesis

SMA: Simple Moving Averages

SSE: Shanghai Stock Exchange

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